PHD

Development of large scale triaxial apparatus for the determination of the shear and damping response of graded granular material subjected to cyclic loads

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DEVELOPMENT OF LARGE SCALE TRIAXIAL APPARATUS FOR THE DETERMINATION OF THE SHEAR AND DAMPING RESPONSE OF GRADED GRANULAR MATERIAL SUBJECTED TO CYCLIC LOADS

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To MUM

ABSTRACT

Previous relevant research and literature is reviewed, along with various testing techniques used to establish the properties of granular materials. The developmental potential of these techniques is examined for their application to the testing of large granular material under dynamic/cyclic conditions. The requirements of the laboratory equipment is established and the design and development of a new large scale triaxial rig capable of sample diameters up to 305mm is described along with the associated sensors and data monitoring system. The testing program involving investigations into the scaling characteristics of testing granular material at different sample diameters - 38mm, 100mm, and 254mm - under static loading conditions indicates that sample size influences the sample response, with the 38mm samples giving lower 'strength' values than the 100mm and 254mm samples which gave good agreement. The new large scale apparatus is validated for the dynamic testing regime and future work described.

ACKNOWLEDGEMENTS

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PREFACE

Due to the developmental and exploratory nature of this project the thesis has been organised into three distinct sections which cover the periods of study associated with the project, with appendicies covering the raw data and areas of interest not directly relevant to the final result.

Part I covers the background material, and previous related research results. Details of the various testing techniques used to establish material parameters, and their development potential is located in this part, in chapter 4. This is to signify the importance of considering the test method used to establish the sample response from which material parameters are derived. This argument is developed in the introduction. Readers familiar with the subject matter may wish to move directly to part II.

Part II deals with the requirements of the laboratory equipment for the project, and covers the design and manufacture of the new experimental apparatus. All the necessary aspects of the data monitoring system and sensors are also included here.

Part III details the laboratory work and testing program to date, the results and consequences. It is here that information pertaining to the tests is located. In order not to clutter the document, all test data is located in Appendix 5. Only relevant examples and cummulatative data is included within the main text.

CONTENTS

PART 3

1.0 INTRODUCTION

With the increasing capacity of modern computers, there is a trend towards the use of ever more complex and detailed analytical procedures in the design of soil structures. However, it must be borne in mind that the accuracy of any analysis, independent of any limitations within the analytical process, is fundamentally dependent upon the accuracy of the material properties entered.

Writers and users of such programs are becoming more removed from the processes, constraints, and limiting assumptions used in the determination of soil properties, from both laboratory tests and in-situ techniques. It is therefore necessary when testing soils to establish properties for analysis and design, to evolve more rigorous techniques and to identify influencing parameters. This will improve the understanding of material behaviour, so that any information derived can be used within the appropriate context.

The objective of the research program of which this thesis is a part, is concerned with investigating the effect of dynamic loading upon large particulate materials. It is of particular relevence to the response of soil structures such as embankments, utilised for dams and transport infrastructure requirements etc., subjected to dynamic loading. The principal source of dynamic loading considered in this work is that due to earthquakes.

Little information has been reported on the dynamic behaviour of large granular material concerning factors such as shear modulus and damping. This seems suprising, since it is the provision of accurate material properties that allows the most economic design in terms of cost and safety. Further, without an accurate understanding of the material behaviour, the designer is relying on essentially arbitary 'factors of safety', and the failure of such structures as embankment dams can be catastrophic in both human and financial terms.

In the past, investigations into the dynamic behaviour of cohesionless materials have in the main been restricted to sands, because, as the individual particle size increases, so does the size of sample required adequately to model the material. The dimensions of traditional equipment has thus limited testing to fine grained material.

A large scale triaxial apparatus has thus been developed as part of this research program, enabling sample diameters up to 305mm, compared with the 38mm and 100mm diameters in standard equipment. The larger sample size allows a wider range of particle size distributions to be examined, with individual particles upto 60mm possible. The maximum individual particle size able to be accommodated within any given sample diameter is also affected by the decision to use either single sized or graded samples. As the particle size increases and the more single sized the sample becomes, the greater the difficulty in achieving a representative failure unaffected by the boundary conditions.

Traditionally, due to the size limitations of testing equipment, when determining the parameters of graded materials involving large particulate matter, only the fines content has been tested. The larger cell allows for the testing of graded samples with a similar grading curve to that of the full size material, but with the grading curve 'shifted' down the size axis. The results can then be compared with tests on the fines content alone.

The use of fines tests to determine the overall behaviour, independant of deformation, for a mixed particulate material, is only justified when the larger particles are fully suspended in a matrix of the fines, and this must be maintained throughout the life of the structure. Deformations of the structure and water seepage may well modify this 'ideal' matrix and so alter the material parameters. Thus data on realistically graded samples will be useful in helping to determine economic design utilising the minimum of material, and possibly reducing the need for over selective grading assemblies at major projects.

To fulfil the requirements of this project, the large triaxial cell needed to be developed, suitable operational methods established, and calibration tests versus the 38mm and 100mm cells performed. Upon the satisfactory outcome of these, was determined the progression onto the static testing of the large grained material followed by the more detailed investigations and dynamic tests. It was felt that the early gradation tests comparing the results on similar sized material tested in different cells required further investigation, as there was some evidence to indicate that the size of apparatus was having an effect. Without fully identifying this aspect the justification of future dynamic tests would be difficult, and certainly lead to problems with the comparable testing between large and small cells. This dramatically affected the timetable, restricting the later testing program.
So whilst this thesis may seem to be out of balance with respect to the background information and the documented

testing, it was the objective of the cyclic results that gave rise to the project and the development of the apparatus. The early chapters place the experimental program in context, and provide the springboard for further work.

PART I

Background material and previous related research results

2.0 MATERIAL PARAMETERS OF INTEREST

2.1 Analytical Methods

Current dynamic analyses of soil structures, generally model the soil as a visco-elastic material, using the familiar spring/dashpot/mass system which results in the following general basic equation

$$M.u'' + C.u' + K.u = f(t) \qquad [2.1]$$

where

$M.u''$ represents the mass and acceleration term
$C.u'$ represents the viscous damping and velocity term
$K.u$ represents the stiffness and displacement term
$f(t)$ represents the loading term as a function of time

In seismic analysis, for a uniform soil, this equation is re-written to take account of the mode of load application via the ground motion as the result of the upward propagation of shear waves, resulting in an equation of the following form

$$\rho(y).\frac{\partial^2 u}{\partial t^2} + c(y).\frac{\partial u}{\partial t} - \frac{\partial}{\partial y}\left[G(y).\frac{\partial u}{\partial y}\right] = -\rho(y).\frac{\partial^2 u_g}{\partial t^2} \qquad [2.2]$$

where

$\rho(y).\frac{\partial^2 u}{\partial t^2}$ is a density and acceleration term

$c(y).\frac{\partial u}{\partial t}$ is a viscous damping and velocity term

$\frac{\partial}{\partial y}\left[G(y).\frac{\partial u}{\partial y}\right]$ is a stiffness and displacement term represented by the shear modulus

$-\rho(y).\frac{\partial^2 u_g}{\partial t^2}$ is a loading term in response to the ground disp. due to earthquake motion

For multi layered soils, lumped mass parameter systems can be employed using matrix methods applied to eqn. 2.1 resulting in the following expression

$$[M].(u'') + [C].(u') + [K](u) = \{R(t)\} \qquad [2.3]$$

where the matrices [M], [C], and [K] are of the order of the number of soil layers considered.

Detailed solutions to these various expressions are well known and described in numerous text books. The important point to note however, is the nature of the material parameters involved, i.e. the damping and stiffness. In seismic and associated analysis, due to the nature of the loading, (i.e. propagation of shear waves) and the material behaviour, the stiffness term is usually represented by the shear modulus, which relates the shear stress to shear strain. The damping capacity of the material is a measure of its ability to absorb energy.

2.2 Damping and Shear Modulus

As previously determined the material properties of most use in the response analysis of soils and soil structures are the shear and damping characteristics. These material properties are normally defined from the hysteretic stress - strain relationship at different strain amplitudes as shown in figure 2.1.

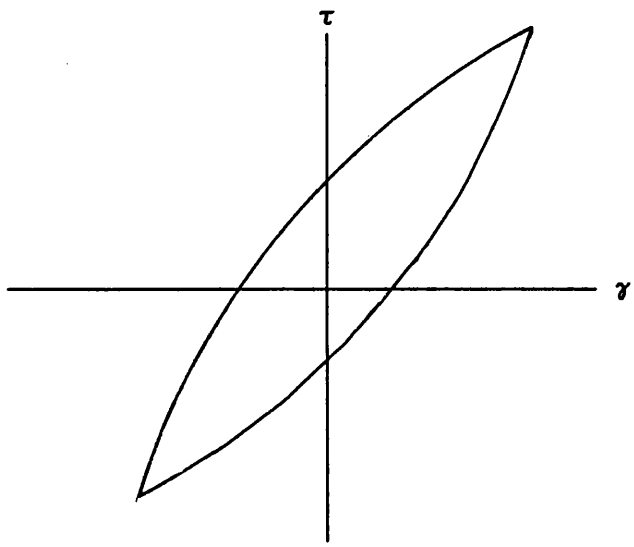


Figure 2.1. Typical stress - strain cycle

2.2.1 Shear Modulus

The shear modulus is the relationship between the shear stress and shear strain and is clearly non linear. However, in order to determine a representative value of shear modulus from each hysteresis loop a line is drawn through the end points, and the gradient of this line is taken as the shear modulus, as shown in figure 2.2, and represents a secant modulus.

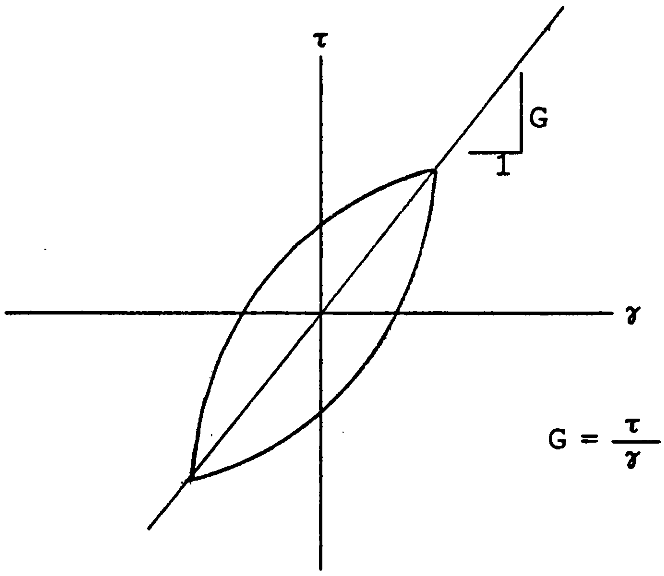


Figure 2.2. Determination of Shear Modulus

If these lines representing the shear modulus and the end point of the hysteresis loop for different strain amplitudes are plotted, then a graph of the form shown in figure 2.3 is produced.

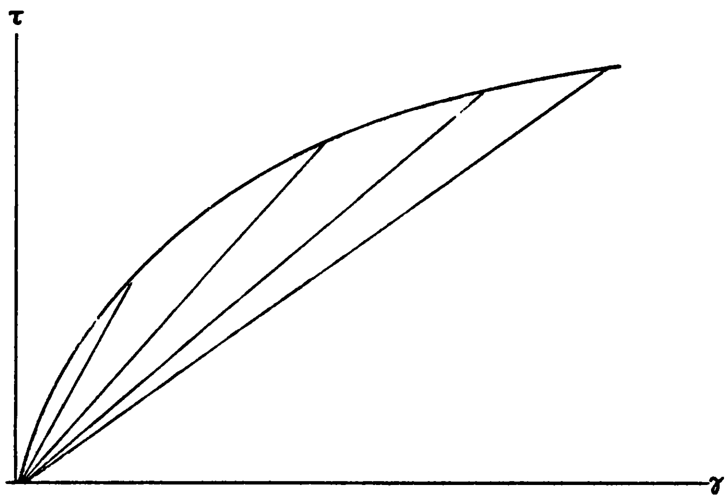


Figure 2.3. Plot of Shear Stress vs Shear Strain amplitude

The representation of data given in figure 2.3 can be used to model the variation of shear modulus with shear strain amplitude, and it was with a hyperbolic relationship that Hardin and Drnevich generated a mathematical model of the soil behaviour, which will be discussed later.

In order to get a more accurate determination of the soil behaviour some analytical procedures attempt to model the stress - strain relationship during each loading cycle more closely. Seed and Idriss (1968) approximated each loading cycle by a bilinear system, shown in figure 2.4, and this coupled with a lumped mass parameter approach has been used in established computer programs (e.g. QUAD 4) in order to determine the response of soil structures to ground motion.

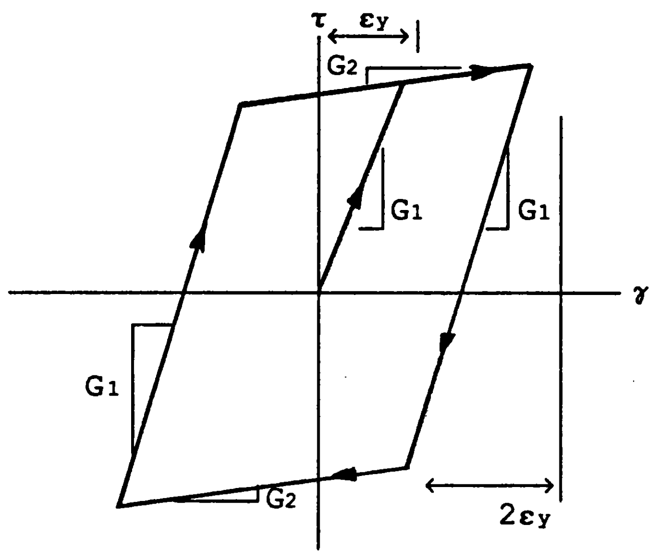


Figure 2.3. Bilinear model from Seed & Idriss (1968)

2.2.2 Damping

The damping, which is a measure of the energy absorbed is less straightforward. It must be noted at this point that we are dealing with the energy dissipated within the soil mass, and not energy lost through any interaction on the foundation boundary. The latter is normally termed radiation damping. Radiation damping is dependent on foundation type and the boundary conditions of the specific design situation, and whilst an important point of consideration often inappropriately dealt with in the design analysis, it is outside the scope of this thesis. With the form of analysis previously described, the damping component was linked to the velocity of the system, which quite clearly presumes a viscous damping coefficient. It is the author's opinion that this is a clear case where the understanding and relative ease of a particular form of analysis has led researchers and engineers into trying to manipulate complex material behavior into a simple all-encompassing coefficient. This in itself is not necessarily a problem, as long as the users are aware of the situation and react accordingly. However, as described in the introduction, there is a tendency for those responsible for design to be ever more removed from the establishment of 'appropriate' material parameters and associated influencing factors.

Damping in soils is a complex issue. Trying to establish an appropriate measure and quantify the 'damping' for a particular soil type needs careful interpretation. It is certainly possible to establish trends and identify the more apparent contributary factors that influence the damping behaviour of soils, but there is an enormous spread in currently available data that attempts to quantify this factor. This may well be due to the way such data is presented, since the issue is generally simplified to represent the damping capacity in terms of an equivalent viscous damping factor.

The typical stress - strain relationship for a granular soil at a given strain amplitude is hysteretic in nature as shown previously in figure 2.1. The area enclosed within the hysteresis loop is a measure of the energy dissipated. The damping is therefore a function of the stress and strain. This response may be influenced by the rate of strain or stress application, but this is a secondary action. However, as described earlier, the nature of current analytical procedures calls for a viscous damping term which depends solely on velocity.

The idea of equivalent viscous damping for a non linear hysteretic system was introduced by Jacobson in 1930. In 1960, applying this principle to composite stuctures, he proposed the following approximate formulae for an equivalent viscous damping factor λ given as a fraction of the critical damping.

$$\lambda \simeq \frac{1}{2\pi} \cdot \frac{W_1}{W_2} \qquad [2.4]$$

where

W_1 = frictional work area

W_2 = work area under skeleton

This relationship is based on the concept of equating the energy loss of a linear visco - elastic system to that of a non - linear hysteretic system when the maximum applied force on both systems is the same.

It is worth noting that Jacobson qualified the formulae with the following comments:

"......that the concept of an equivalent viscous damping is not easily applied to arbitary non - linear systems....."

and goes on to say:

"....the problem of finding an equivalent viscous damping coefficent ratio involves additional debatable assumptions..."

Notwithstanding these reservations the concept of an equivalent viscous damping ratio has become the standard method of quantifying the soil damping for use in response analysis. The standard formula for the determination of this damping factor is as follows, related to figure 2.4, and is essentially Jacobson's 1960 expression.

$$\lambda = \frac{1}{4\pi} \cdot \frac{A_1}{A_2} \qquad [2.5]$$

where

λ = Damping factor

A_1 = Area enclosed by hysteresis loop (1-2-3-4-1)

A_2 = Elastic work done. (area 0-3-5-0)

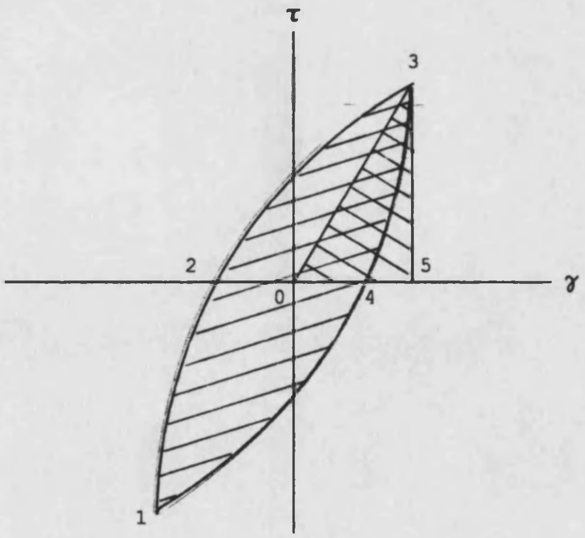


Figure 2.4. Definition of areas for determination of damping ratio.

It could be argued that there is a case for considering alternative approaches to the problem of assessing the dynamic response of soils; in particular to move away from the standard response analysis based on equation 2.1, and thus remove any ambiguity over concepts of equivalent viscous damping, and for that matter the ever changing shear modulus during a given loading cycle. Any such approach would have to balance the complexity of analysis against any improved modelling of the soil behaviour. The current approach has grown out of a confidence in the understanding and relative ease of the analytical solutions, balanced against problems attached to the justification of material parameters.

Notwithstanding these arguments, this thesis is concerned with the experimental determination of material parameters and expanding the current data base, within the current framework of analysis. As long as the basic source data is available, and influencing factors noted, such data can be utilised and adopted within various analytical models. The use of data from experimental sources must always consider the techniques involved, both in terms of the equipment used and theoretical concepts utilised in the extraction of meaningful results. This thesis will be looking at the scaling characteristics of particulate matter and there is a need to be aware that existing viscous models may no longer apply at the new scales being considered here.

This will be discussed as appropriate when considering the results.

3.0 PREVIOUS DATA ON DAMPING AND SHEAR MODULUS

Investigations into the effects of dynamic loading on cohesionless soils have, in the main, been restricted to sands.

The bulk of data published to date on dynamic loading of large particle granular material has dealt with base materials for highway design. These papers deal with the long term effect upon the deformation characteristics of the material, so data is presented in the form of pseudo elastic moduli analogous to Youngs modulus after a large number of load repetitions. Such loading does not simulate earthquake and other short term or large strain loading conditions very closely, and the moduli determined are not very satisfactory for seismic analysis. Further, the material properties established tend to stabilise to equilibrium values after large numbers of loading cycles, which short term dynamic events do not allow.

The material properties of most concern when dealing with seismic loading are the dynamic shear modulus and equivalent damping ratio, and as already discussed they are defined from the hysteretic stress - strain relationship at different strain amplitudes. Where the dynamic shear modulus (G) is expressed as the secant modulus determined by the extreme points of the hysteresis loop and the damping ratio (λ) is proportional to the area within the hysteresis loop.

As can be seen from figure 3.1, both these factors are strongly affected by the shear strain amplitude.

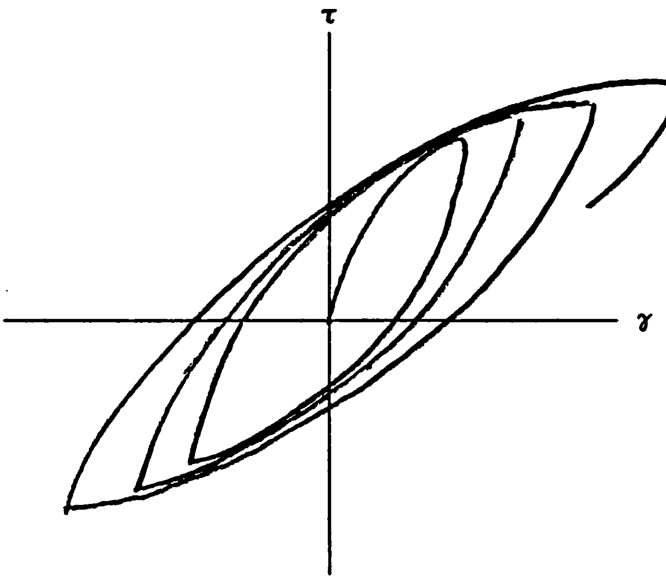


Figure 3.1. Variation of stress-strain relationship with shear strain ampliude.

However many other factors have been shown to influence these parameters to varying degrees.

3.1 DYNAMIC SHEAR MODULUS FOR SANDS

Work carried out by Silver and Seed (1969) showed that the shear modulus was highly dependent on the shear strain and vertical stress. For a given cyclic shear strain, the shear modulus increased with vertical stress, and as shear strain increased, the value of shear modulus decreased significantly, as is apparent from the earlier explanation of these factors. The relative density was also found to influence the shear modulus, with increasing relative density giving larger values of shear modulus at any given shear strain.

Silver and Seed also noted that the number of stress cycles influenced values of shear modulus, greater number of stress cycles leading to a higher modulus. But this effect was greatest in the first 10 cycles, after which changes were fairly small.

They further noted, relating shear modulus (G) and vertical stress (σ_v) in the form represented by a straight line on a log-log plot, in the form

$$G = k_m . \sigma_v^m \qquad [3.1]$$

that values for the exponent (m) varied between 0.5 and 0.7, depending on the shear strain amplitude , m increasing with shear strain.

A comprehensive study by Hardin and Drnevich (1972), investigating the behaviour of soils, suggested that the primary factors affecting the shear modulus characteristics for clean dry sands were as follows

strain amplitude

effective mean principal stress

voids ratio

and less important factors included

effective strength envelope

no. of cycles of loading

octahedral shear stress

Factors such as overconsolidation ratio, frequency of loading, time effects, grain characteristics, and soil structure were found to be relatively unimportant.

Hardin and Drnevich showed that the modulus decreases very rapidly with strain amplitude with no apparent cut off strain level below which the modulus is constant. However, for 'practical purposes' they proposed that the modulus measured for strain amplitudes less than $2.5*10^{-5}$ could be taken as equal to the maximum value for the shear modulus (G_{max}).

Increasing the effective mean principal stress was found to lead to an increase in the modulus at a given strain amplitude; further, the effect of changing the number of loading cycles seemed to increase as the effective mean principal stress increased, with increasing number of loading cycles causing an increase in modulus. This latter effect was more pronounced within the first ten loading cycles than above. There was very little change when the number of loading cycles increased from 10-100, supporting the findings of Silver and Seed (1969).

With the relationship between shear modulus (G) and mean principal stress ($\bar{\sigma}_o$) expressed in the following form,

$$G_{max} \propto (\bar{\sigma}_o)^n$$

the exponent n was found to vary with shear strain amplitude. At very low shear strain amplitudes when the value of shear modulus approaches G_{max}, n was 0.5

$$G_{max} \propto (\bar{\sigma}_o)^{0.5}$$

and at higher strain amplitudes, the value of n approached 1.0,

$$G_{max} \propto (\bar{\sigma}_o)$$

From their results, Hardin and Drnevich proposed a series of equations which would allow the determination of the shear modulus at any strain amplitude. Simplified for cohesionless materials, these are as follows :

$$G_{max} = 14760 \frac{(2.973-e)^2}{1+e} . (\bar{\sigma}_o)^{0.5} \quad \text{units psf} \qquad [3.2]$$

where

G_{max} = max shear modulus in psf

e = voids ratio

σ_o = mean principal effective stress in psf

the modulus value (G) at any strain level (γ) is then evaluated from

$$G = \frac{G_{max}}{1+\gamma/\gamma_r} \qquad [3.3]$$

where

$$\gamma_r = \frac{\tau_{max}}{G_{max}} \qquad [3.4]$$

and

$$\tau_{max} = \left(\left(\tfrac{1}{2}\left(1+K_o\right).\sigma_v'.\sin\phi\right)^2-\left(\tfrac{1}{2}\left(1-K_o\right).\sigma_v'\right)\right)^{0.5} \qquad [3.5]$$

where

K_o = coefficient of lateral earth pressure at rest

σ_v' = vertical effective stress

ϕ = effective angle of friction

This method is based on the precept that the shear stress - shear strain relationship can be modelled as a hyberbola as shown in figure 3.1. The apparent complexity of this procedure leads to a feeling of security for the accuracy of the results. But it must be noted that the factors involved in the equations are open to interpretation. K_o is usually a difficult parameter to establish with certainty, and decisions need to be taken as to whether peak, ultimate or residual values of ϕ are appropriate.

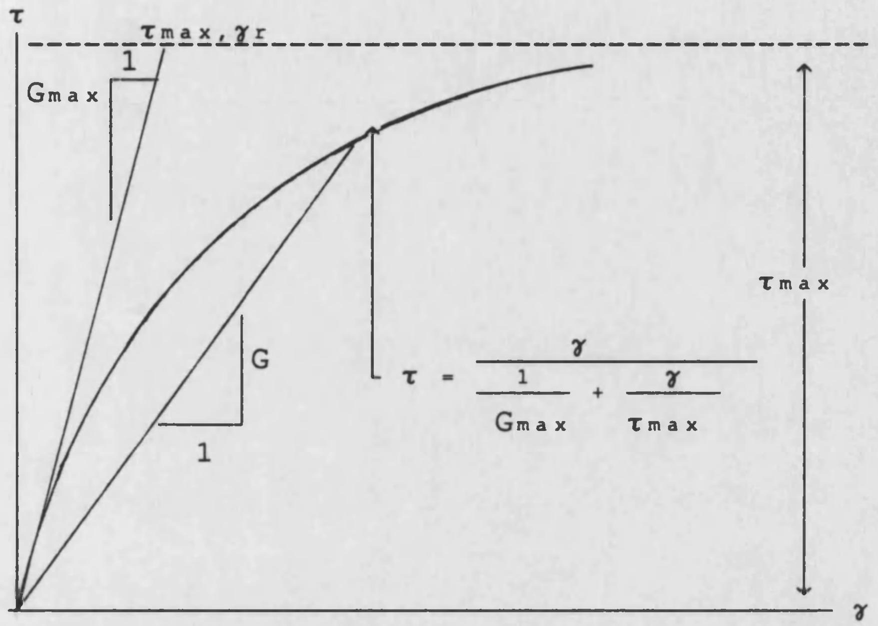


Figure 3.1. Hyperbolic stress-strain relationship

Seed and Idriss (1970) made a detailed parametric evaluation of these equations and proposed a simplified expression for the dynamic shear modulus of sands -

$$G = 1000.K_2.(\sigma_o')^{0.5} \quad \text{units psf} \quad [3.6]$$

where

G = shear modulus
σ_o' = effective mean stress

and where the influence of various factors are shown through their effect on K_2.

Using the Hardin and Drnevich equations, Seed and Idriss found that the effect of the various influencing parameters depended on the strain amplitude and could be summarised by describing their effects on K_2 at low, intermediate, and high strain amplitudes.

1. At very low strains ($\leq 10^{-5}$), K_2 depended only on void ratio.
2. At intermediate strains (10^{-5} to 10^{-3}), K_2 was only slightly influenced by vertical stress, ø, and K_o, but strongly influenced by void ratio.
3. At very high strains ($>10^{-3}$), K_2 was slightly influenced by vertical stress, but essentially independent of K_o, ø, and void ratio.

They thus concluded that for most practical purposes, K_2 could be considered to be determined mainly by void ratio or relative density and the strain amplitude.

Having introduced this factor K_2, Seed and Idriss noted the results of laboratory tests on samples at different relative densities at very low strains and found values of K_2 in the range of 50 - 75. The general form of K_2 with changing relative density and shear strain is shown in figure 3.2.

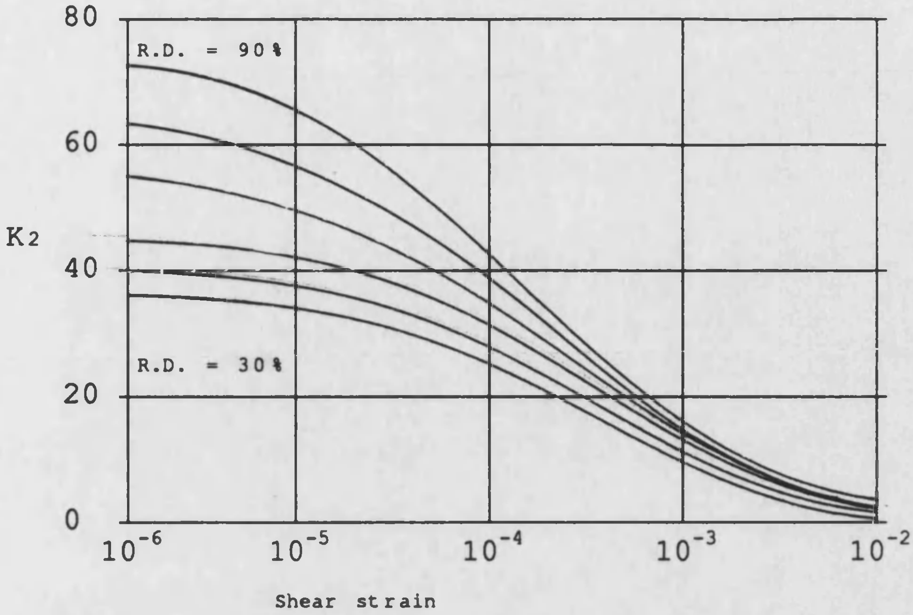


Figure 3.2. Variation of K_2. After Seed and Idriss (1970)

Comparing these values of K_2 determined from laboratory tests, with values derived from in-situ investigations using shear wave velocity measurements at very low strain levels on dense to extremly dense sands, Seed and Idriss noted favourable agreement, with the in-situ results giving values of K_2 ranging from 44 - 86.

Using the Hardin and Drnevich equations to establish values of K_2 analytically, with $\bar{\sigma}_o$ = 144 kN/m^2 (3000psf) K_o = 0.4, and ϕ = 36°, Seed and Idriss showed the change of K_2 with shear strain in terms of void ratio as shown in figure 3.3.

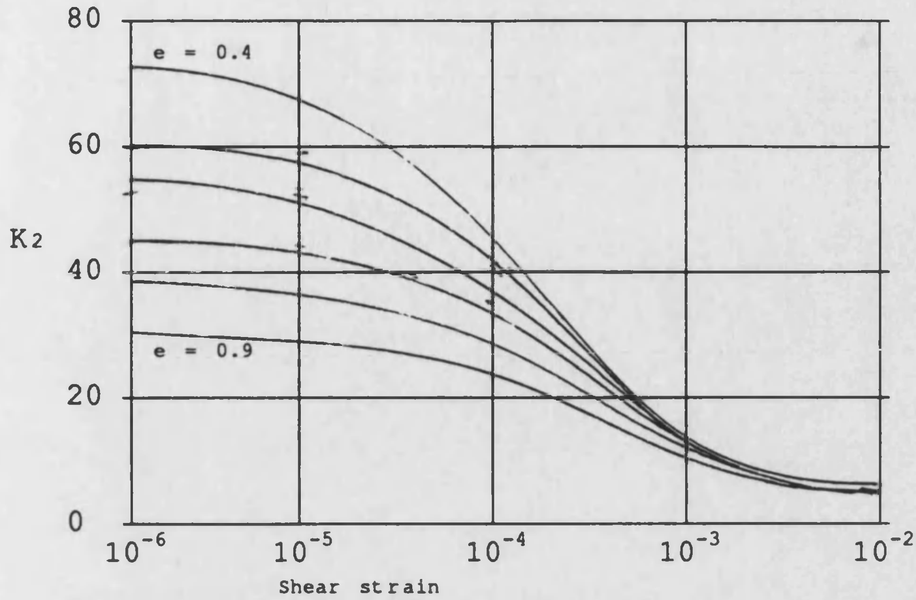


Figure 3.3. Variation of K_2. After Seed and Idriss (1970)

This showed good agreement with the laboratory results described in figure 3.2. Replotting the data from both experimental and analytical procedures to show the variation of shear modulus with shear strain, and normalising the shear modulus with respect to the maximum shear modulus found at very small shear strains (10^{-6}), Seed and Idriss produced the result shown in figure 3.4.

The data fell within a narrow band and Seed and Idriss thus concluded that a close approximation to the modulus for a sand at any given shear strain could be obtained by determining the shear modulus at very low strains (to establish the maximum value) and then reducing this value for larger strains by using 'reduction factors' indicated by the mean line shown in figure 3.4.

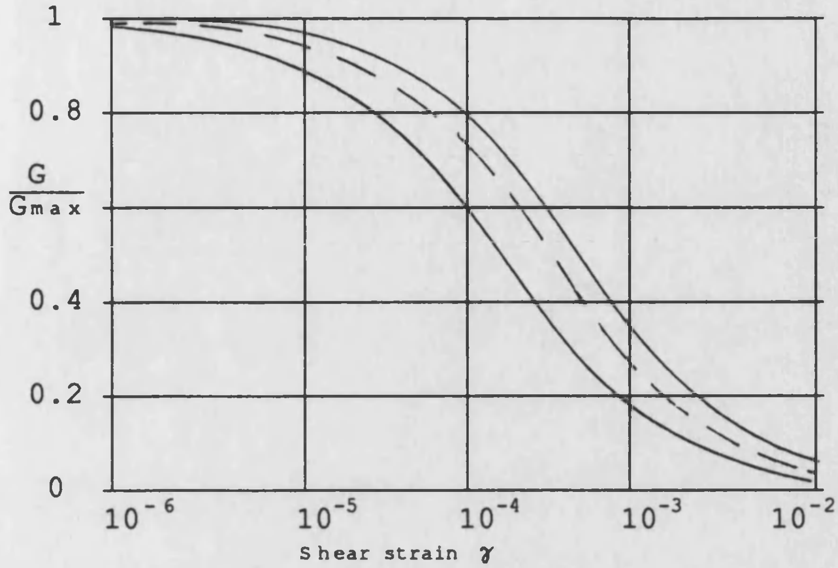


Figure 3.4. Range of data shown in figures 3.2 & 3.3. After Seed and Idriss (1970)

Reporting on cyclic tests on Toyoura sand, Kokusho (1980) confirmed a similar relationship between shear modulus and shear strain as proposed by Seed and Idriss, showing that the modulus converges to a maximum as the strain falls below 10^{-5} - 10^{-6} and decreases as the strain increases.

For a given shear strain, Kokusho found the value of shear modulus increased with confining stress, as noted by Hardin and Drnevich, and that the number of stress cycles had little effect. Normalising the shear modulus with respect to the shear modulus at 10^{-6} shear strain, again showed a similar pattern to that obtained by Seed and Idriss. But, as confining stress increased, the curve corresponding to each confining stress shifted consistently to the right, along the shear strain axis, indicating that for a given shear strain as confining stress increases so also does the shear modulus.

Seed et al (1986) reported that the results of Shibata and Soderno (1975) and Iwaski et al (1976) showed that the modulus attenuation curve for sand was influenced by confining stress. This gives some confirmation of Kokusho's results.

Kokusho noted that the effect of void ratio was again similar to that found by Seed and Idriss, i.e. increasing void ratio gave lower shear modulus for a given shear strain. But when the normalised modulus ratio G/G_{max} was plotted, void ratio had less influence than the confining stress.

In comparison with other data, Kokusho noted that his results followed very closely in form to those reported by Richart, Hall and Woods (1970) who investigated sands with round grains, but differed numerically by approximately 20%, hence whereas Richart, Hall and Woods proposed

$$G_{max} = 700.\frac{(2.17 - e)^2}{1 + e}.\ (\sigma'_c)^{0.5} \qquad \mathrm{Kgf/cm^2} \qquad [3.7]$$

Kokusho suggested -

$$G_{max} = 840.\frac{(2.17 - e)^2}{1 + e}.\ (\sigma_c')^{0.5} \qquad Kgf/cm^2 \quad [3.8]$$

Plotting $G/(2.17 - e)^2/(1 + e)$ vs σ_c' on a log graph revealed straight line relationships with the slope increasing with strain, indicating that the modulus vs confining stress relationship could be formulated as -

$$G \propto (\sigma_c')^m \qquad [3.9]$$

where, m denotes the slope of each line, as noted by previous researchers but expressed in terms of vertical stress, i.e. Silver and Seed (1969).

For the strain range 10^{-6} to $3*10^{-3}$ values of m varied from 0.47 to 0.84. This compares with similar findings by Iwaski et al (1976), which gave values of the exponent m in the same strain range of 0.38 to 0.97, and the trend reported by Hardin and Drnevich of values ranging between approximately 0.5 to 1.0; in terms of effective mean stress.

Seed et al (1986) presented a relationship modified from an expression proposed by Ohta and Goto (1976) between maximum shear modulus (G_{max}) and mean effective stress (σ_m') and SPT N-values of the form -

$$G_{max} \simeq 1000.20.(N1).(\sigma_m')^{0.5} \qquad \text{units psf} \qquad [3.10]$$

which is similar to equation 3.6 if

$$K_2 \simeq 20.(N1) \qquad [3.11]$$

Using this equation for values of N1 = 5 for loose sands to N1 = 44 for dense sands gave values of K_2 ranging from 34 - 71 which compares favourably with in-situ shear wave velocity measurements giving values of K_2 between 34 - 86 and the laboratory and analytical results previously described.

3.2 DAMPING RATIO FOR SANDS

Silver and Seed (1969) reported that the hysteretic damping increased with increasing shear strain amplitude, but decreased with increasing vertical pressure at any given shear strain. This latter effect, however, was much more pronounced at pressures below ≃ 48 kN/m^2 (1000psf) . The general form of the relationship is shown in figure 3.5.

Further, Silver and Seed reported that the relationship between damping and shear strain was essentially independent of the relative density, and that increasing the number of loading cycles tended to decrease the damping slightly.

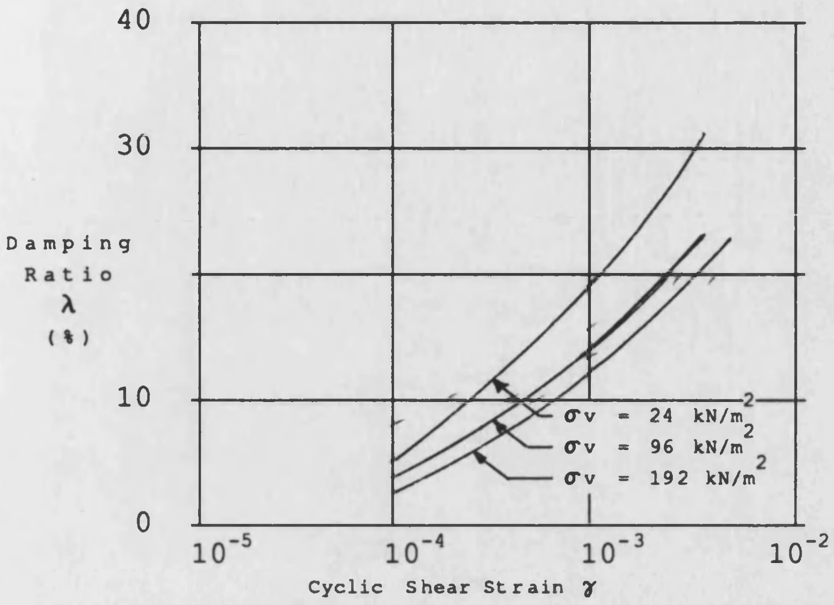


Figure 3.5. Variation of damping ratio vs shear strain after Silver and Seed (1969)

A comprehensive study by Hardin and Drnevich (1972) investigating the behaviour of soils, suggested that the primary factors affecting the damping characteristics for clean, dry sands were :

strain amplitude
effective mean principal stress
void ratio
no. of loading cycles

and that less important factors included effective stress envelope

octahedral shear stress

Factors such as overconsolidation ratio, frequency of loading, time effects, grain characteristics, and soil structure were determined to be relatively unimportant.

They found that the damping ratio increased with strain amplitude, with very small values at low strain amplitudes and increasing to an asymptote termed D_{max} at high strain levels.

The effect of increasing mean principal stress at a given strain amplitude, was found to lead to a decrease in the damping factor. Increasing the number of load repetitions was also found to decrease the equivalent damping factor. If one considers the damping of the soil to be a function of its ability to deform, then these effects are to be expected. Both actions lead to a higher density, thus stiffening the material.

From the results of their investigations, Hardin and Drnevich proposed the following equations for the determination of the damping ratio (λ), at a strain level (γ) :

$$\lambda = \frac{\lambda_{max} \cdot \gamma/\gamma}{1 + \gamma/\gamma_r} \qquad [3.12]$$

where γ_r = reference strain, as determined from equation 3.4,

and λ_{max} is the maximum damping ratio corrisponding to very large strains, and for clean sands is :

$$\lambda_{max} = D - 1.5 \log_{10} N \quad \% \qquad [3.13]$$

where D = 33% for clean, dry sands

D = 28% for clean, wet sands

A similar parametric study by Seed and Idriss (1970) as previously discussed regarding shear modulus, was carried out to determine the effect of variations in the factors mentioned by Hardin and Drnevich as influencing the damping characteristics. This showed that changing ϕ, K_o, e , and %sat. had relatively minor effects, and considering the equation given for λ_{max}, that within the range of values of N of interest (1 - 30) values of λ_{max} would not be significantly different.

Considering variations in pressure, Seed and Idriss concluded that for pressures below $\simeq$ 24 kN/m^2 (500 psf) which would only apply to the top few metres of deposit, pressure changes may be significant, but that above this figure the effects of changes in pressure were small compared to the effect of shear strain upon damping. They suggested an average damping ratio vs shear strain relationship for effective vertical stresses between ≈ 96 - 144 kN/m^2 (2000 - 3000 psf). This relationship follows the form shown in figure 3.6 , and compares favourably with data achieved from laboratory testing presented at that time.

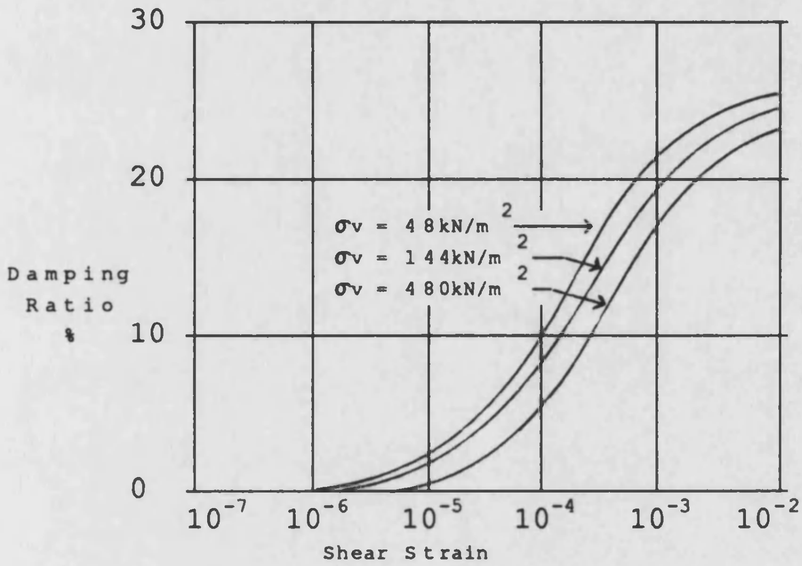


Figure 3.6. Variation of Damping ratio vs Shear strain After Seed and Idriss (1970)

Kokusho (1980) found the same form of relationship to that proposed by Seed and Idriss and noted that void ratio had little effect, although the curve shifted slightly to the left on the shear strain axis as void ratio increased, indicating an increase in damping at any given strain as density decreased. This is opposite to the behaviour reported by Seed and Idriss (1970). However, as confining pressure increased, the curve was consistently translated to the right along the strain axis, indicating a decrease in damping as confining pressure increased.

3.3 DYNAMIC SHEAR MODULUS FOR GRAVELLY SOIL

Reporting on a few in situ shear wave velocity measurements on gravelly soils, Seed and Idriss (1970) noted that these indicated modulus values at low strain levels between 1.25 and 2.5 times greater than for sands. They futher suggested that the moduli would decrease in a similar manner as for sands, as the shear strain amplitude increased.

As noted earlier, there has been little laboratory work on the dynamic shear modulus vs shear strain relationship for gravels. and as such there is little experimental evidence to report.

However, Seed et al (1980) reported the results of cyclic triaxial tests carried out on large diameter (12") samples of several gravelly materials. These included :

> Oroville gravel which was well rounded, while the fine particles were subrounded to subangular and very hard.
>
> Pyramid dam Rockfill whose particles were very angular in shape and could be broken with a hammer.

Venado sandstone which contained fine - medium, very angular particles which were very weak.

Livermore natural gravel, with well rounded to rounded particles which were relatively hard.

Using the relationship proposed by Seed and Idriss (1970) (see equation 3.6), Seed et al presented their data in terms of the factor K_2.

The results showed that K_2 decreases markedly as the cyclic shear strain increases, and the effect of increasing relative density is to increase the value of K_2 at any given shear strain, although this latter effect was less pronounced at higher strains. The maximum values of K_2 for the materials tested by Seed et al, ranged between 75 - 135 depending on relative density and hardness of particles.

Using equation 3.6 to establish values of K_2 from in-situ shear wave velocity measurements, indicated values for K_2 in the range 90 - 190.

Normalising the modulus values with respect to the maximum shear modulus attained at shear strains of the order of 10^{-6} yielded a similar 'modulus attenuation' with strain amplitude as found with sands, although the relationship is slightly flatter as shown in figure 3.7.

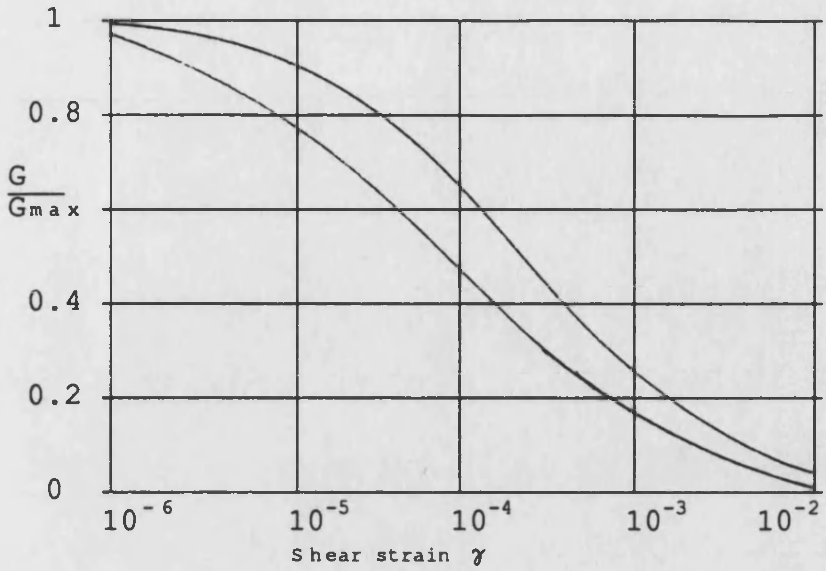


Figure 3.7. Modulus attenuation curve for gravels. After Seed et al (1986)

Seed et al reported that the effect of gradation did not appear to be a significant factor, as there was only a maximum 10% difference between the results from the largest and smallest particle material, with this effect reducing as strains increased. No comment was made regarding any effect the angularity of the particles may have had on the response of the samples.

Kokusho (1981) reported the results of a series of cyclic tests on two kinds of course grained material: one a crushed rock of angular particles, the other a rounded river washed gravel.

The modulus values for the crushed rock were noticeably greater than for the rounded gravel at low strains, although this difference reduced considerably at higher strains. The decrease in modulus as the strain increased for the crushed rock was much more drastic than that for the rounded gravel.

The maximum modulus values for the two coarse grained materials tested by Kokusho, exceeded the values for dense Toyura sand at equivalent confining stresses by factors between 1.25 to 1.7 for the rounded gravel, and 2.4 to 3.0 for the crushed rockfill. This compares well with the findings of in-situ shear wave velocity measurements.

Since the two coarse grained materials differed little in terms of density and grain size, Kokusho suggested that particle shape and angularity appeared to play a significant part in the determination of shear modulus for course grained materials at low strain levels

Although Seed et al made no comment on the possible effects of angularity of the particles in their tests, using the material descriptions given in the papers allows comparisons to be made. The Livermore rounded material showed lower values of shear modulus than the angular Pyramid material, which supports the comments made by Kukosho regarding the effect of angularity. The Oroville gravel was apparently less angular than the Pyramid material, yet it showed higher values.

However these two materials further differed in terms of particle size, the Oroville material having the larger particles and possibly a more even particle distribution, and also in terms of individual particle strength with the Oroville particles being stronger.

3.4 DAMPING AND GRAVELLY SOILS

Again, very little data has been published. Reporting on the tests carried out on the material described in the previous section, Seed ėt al (1986) found that the equivalent damping ratios were similar for the different materials tested.

This would seem to indicate that material gradation and individual particle strength has little effect upon the damping of a particulate material. The influence of relative density amongst the different materials appeared limited and inconsistent. However when the values for damping ratio for all the materials were averaged, a trend related to relative density did emerge, with increasing relative density leading to larger values for the damping ratio. This correlates with a similar effect noted by Kukusho for sands but opposite to that reported by Seed and Idriss (1970).

Comparing the data from their tests on gravels to the limits proposed by Seed and Idriss (1970) for sands, Seed et al found good agreement.

Thus it would appear there is little difference in the values of damping between sands and gravels, although there are intriguing disparities on the effect of relative density, with some researchers reporting an increase in damping with increasing density whilst others indicate the opposite. However bearing in mind the spread in the data reported for sands, and the lack of data for gravels, it is difficult to reach any conclusions regarding any comparison. At this point it is worth bearing in mind the interlocking nature of graded samples versus single sized samples, and the effect upon the damping such differences would have.

3.5 SUMMARY REGARDING DYNAMIC SHEAR MODULUS

All reported data confirms the high dependency of dynamic shear modulus upon shear strain amplitude, stress level and void ratio (relative density).

The effect of increasing shear strain is to decrease the shear modulus (G). Maximum values of G are found at very low strains of the order of 10^{-6}, with the modulus decreasing rapidly through strains 10^{-5} to 10^{-3}, and levelling off at higher strains.

The stress level has been related through either the effective mean principal stress ($\bar{\sigma}_m$), or confining stress (σ_c), or vertical stress (σ_v). Increasing these factors leads to an increase in shear modulus. However, the rate of increase in shear modulus depends on the level of shear strain amplitude, related in the form -

$$G \propto (\bar{\sigma}_m, \text{ or } \sigma_c, \text{ or } \sigma_v)^m \qquad [3.14]$$

where the values of the exponent (m) vary through 0.38 - 0.97 with increasing shear strain amplitude. Most researchers relate G_{max} at small strains to a value of $m = 0.5$.

At any given shear strain, increasing the relative density (decreasing void ratio) leads to an increase in shear modulus.

The number of loading cycles has been shown to have a slight influence on the shear modulus. Increasing the number of loading cycles tends to raise the modulus value, although this is most noticeable in the first 10 cycles with little effect thereafter.

When the normalised modulus ratio G/G_{max} vs shear strain relationship is plotted, the data falls within narrow limits with G/G_{max} increasing slightly with stress level at any given shear strain.

The general relationship between shear modulus and shear strain for gravels is very similar to sands but the normalised G/G_{max} vs shear strain relationship appears slightly flatter.

Quantitatively, in-situ shear wave velocity measurements have indicated that shear modulus values for gravelly soils are between 1.25 and 2.5 times greater than for dense sands, and the limited laboratory data available tends to corroborate this.

A number of researchers have presented explicit relationships for G_{max} at very low strain levels, e.g. Richart, Hall and Woods (1970), Hardin and Drnevich (1972), Seed and Idriss (1970), Kukosho (1980), and Seed et al (1986), this latter relationship being a direct development of that presented by Seed and Idriss (1970). But only Hardin and Drnevich (1972) and Seed and Idriss (1970) (and Seed et al 1986) have indicated methods of establishing values of shear modulus at any strain amplitude. That presented by Seed and Idriss is the most straightforward, but requires knowledge of the factor K_2, which, as the data base stands at the moment concerning gravelly materials, is very limited. Although equation 3.11 may enable correlation with standard SPT values.

3.6 SUMMARY REGARDING DAMPING

All reported data on the equivalent damping ratio for granular materials show its dependency on shear strain amplitude and the same general form of the relationship. i.e. very low values of damping at shear strains of the order 10^{-6}, with the damping increasing rapidly through shear strains 10^{-4} to 10^{-3} and appearing to level off at large shear strains around 10^{-2}.

The laboratory determination of damping ratios has been characterised by a wide degree of scatter, even within the data reported by the same researchers using the same apparatus. So it is difficult to reach any definitive conclusions about the influence of various factors. It is worth noting at this point that the determination of damping values is highly dependent on the testing method employed. Some techniques rely on the manipulation of mathematical models, whilst others rely directly on the stress - strain measurements themselves. This is covered in more detail in section 4.0.

Most reports have indicated that increasing the stress level decreases the damping at a given strain amplitude.

This effect appears most significant at lower values of stress, and bearing in mind the scatter in the data, Seed and Idriss (1970) concluded that as far as sands are concerned, the average damping relationship at $\sigma_v \simeq$ 90 - 140 kN/m^2(2000 - 3000 psf) would be adequate for most purposes.

Regarding gravels, the data so far published falls within the limits previously determined for sands, with any effects of gradation and individual particle strength being obscured by the spread of data. The effect of relative density appears to be inconsistant.

Thus, there appears little difference in the damping ratios between sands and gravels, although due to the scatter of results this confirms little other than that the damping ratio in cohesionless soils increases up to approx 30 - 40 % with increasing strain.

For particulate cohesionless materials, the published data shows that within the range of strains applicable to seismic conditions (10^{-4} - 10^{-2}) values for the damping ratio differ by as much as 500% at any given shear strain, ranging from 3% at the lower strain range to as high as 28% at higher strains. This makes it impossible to give precise quantitative values for design purposes.

4.0 DETERMINATION OF PARAMETERS

When dealing with material parameters it is important to be aware of the procedures and processes employed in their determination. There are various ways and means of expressing, and establishing the response of materials, and these often have a bearing on the interpretation and manipulation of the data into material properties. As this thesis required the development of a new piece of testing apparatus it is necessary to consider appropriate testing methods and their influence on the data produced.

This chapter outlines the various laboratory methods available, and those employed to produce the results detailed in the previous chapters. These techniques are discussed in terms of their development potential for testing large grained particulate material. In-situ tests are briefly covered, as results from these methods have been used in the in the past as verification of laboratory tests.

4.1 IN-SITU TESTS

The in-situ determination of the dynamic properties of soil rely on the inducement of ground motion and measurement of the soil response. The material parameters can then be determined from equations that relate the speed of the induced vibrations to the material property required via mathematical models.

The dynamic shear modulus can be determined from the measurement of the shear wave velocity using the following equation -

$$v_s = \sqrt{G/\rho} \qquad [4.1]$$

where

v_s = shear wave velocity determined from field tests

G = Dynamic Shear modulus

ρ = material density

However, this technique of measuring the shear wave velocity from induced ground vibration gives a value for the shear modulus (G) corresponding to G_{max}. This is due to the fact that the vibrations induced within the soil are at very low strain levels. This method is therefore not suitable for determining the relationship of shear modulus with increasing shear strain. Results from these tests have been used to confirm laboratory and analytical values for G_{max} determined at low strain levels.

4.2 LABORATORY TECHNIQUES

There are many methods of determining the dynamic shear modulus and damping of soil samples in the laboratory.

Triaxial compression, and simple shear tests conducted under cyclic loading conditions provide hysteretic stress - strain relationships for samples, and thus allow direct determination of the modulus and damping.

Forced vibration tests, such as the application of longitudinal or torsional vibrations to cylindrical samples or shear vibrations to layers of soil on shaking tables, allow the investigation of the response of samples at various frequencies. Material properties such as the dynamic shear modulus can be determined from various mathematical models that relate these factors to the natural frequency.

Free vibration tests where measurements are taken of the decay in response of a soil sample to certain excitation loadings allow the determination of a damping value. Use of mathematical models that relate the logarithmic decrement factor to the damping ratio give a damping value that may be compared with that determined from constant amplitude vibration tests. But, once again, account needs to be taken of the validity of the mathematical representations used.

4.2.1 Resonant Column Method

This is a forced vibration test allowing either longitudinal or torsional excitation. The longitudinal vibration tests allow the determination of Young's modulus, whilst the torsional vibration tests are used to determine the shear modulus.

A soil sample, usually a cylindrical column, is vibrated in torsion to determine its resonant frequency, from this the appropriate wave velocity can be established and hence the shear modulus.

A variety of resonant column devices have been used by researchers in the past. The major differences between these devices that relate to the interpretation and determination of the modulus from the results are the constraints applied to either end of the soil sample. These factors are important since the equations used to establish the modulus are derived from response calulations in which the end conditions need to be modelled appropriately. End conditions used previously are free - free (in other words the specimen is modelled as unrestrained at either end), and fixed - free (in which the specimen is modelled as being fully restrained at one end and unrestrained at the other). An example of the type of expression derived for the fixed - free end condition is given below

$$G = 39.48 \ (f_n^2 \ L^2/\alpha^2) \ \rho \qquad [4.2]$$

and $$\alpha = \omega_n \ L/v_s \qquad [4.3]$$

where

G = Dynamic shear modulus

f_n = Undamped natural frequency

L = Height of sample

ρ = Density of material

ω_n = Undamped natural circular frequency

v_s = Shear wave velocity

A feature of torsional excitation within these devices is that the shear strain within the sample varies from zero at the central axis of the sample to a maximum value at the perimeter of the sample. Thus when testing solid samples only very low strains can be applied and the values of shear modulus determined relate to G_{max}. To overcome this limitation hollow samples can be used to assess the response at high strains. However, the thickness of the sample needs to be kept as small as possible, since there will still be a variation of shear strain between the inner and outer diameters of the sample. Hollow samples incur additional complexity in the loading and pressurising system, related to the internal and external pressures of the sample, and set up a complex regime of surface stresses on the sample.

Due to the complexity of the end plattens of these devices the samples often have to be prepared within a separate triaxial cell.

A value for the damping capacity of soil samples can also be determined from the resonant column test by making use of the logarithmic decrement factor. Once a sample has been set into steady state vibration the driving force is removed and the amplitude of vibration allowed to decay. The decay vs corresponding number of cycles can be plotted, and the logarithmic decrement factor evaluated from the gradient of the resulting straight line. Note that a correcting factor must be applied to take into account the effect of any mass that the apparatus may place on the sample. As explained in section 4.2, further numerical models are required if the decay of free vibrations is to be related to damping at constant amplitude.

4.2.2 Triaxial Cell Apparatus

This is an established piece of apparatus much used within geotechnical laboratories. In its simplest form it is essentially a pressure cylinder within which a sample of soil can be sustained at an all round confining stress and an additional vertical force is applied to the sample within the cell. The cylinder (or cell) can become more complicated with the addition of special drainage plattens, drainage lines, and fitments for the measurement of the sample response (i.e. load and displacement) etc within and external to the cell.

The traditional apparatus allows for samples of 38mm diameter, which limits possible sample materials to fine grained sands, silts, and clays. Cells capable of taking samples up to 100mm in diameter are available but less common, which allow the testing of coarser sands and possibly very fine gravels.

The loading method employs an all round confining stress with provision made for the application of an additional vertical force to be applied to the sample, usually via a loading ram passing through the cell to an external loading device.

Using these devices, a sample's response to dynamic loading can be recorded and stress - strain relationships plotted from which the damping and shear modulus can be determined directly. There are no limitations on the strain amplitudes that can be applied to the sample inherent to the technique itself, although researchers have reported some difficulty at very low strain levels. This seems to be related to the difficulty in actually measuring the very small responses from the sample at such low levels of strain. As use of this apparatus requires the suitable determination of the stress-strain of the sample, the technique relies on actual measurement of the sample's axial and radial deformation, and of the load applied to the sample. Traditionally, such measurements are made external to the cell, relying on the transfer of the sample's response through the mechanism of the apparatus. At very low strain levels this is inappropriate and methods that allow measurement on the sample within the cell are required.

There is no inherent limitation in the technique in terms of the size of sample that can be tested, other than the need to build a cell capable of holding it, thus large grained particulate material may be tested using this method. In fact most dynamic testing of large grained material uses this method, although some Japanese research has used shaking tables.

When using the triaxial cell apparatus it must be noted that the stresses set up within the soil sample do not model seismic loading conditions very well. This can be overcome by careful assessment of the loading conditions and adapting the results accordingly.

The triaxial cell apparatus is used for a wide variety of testing requirements under static loading conditions, and is probably one of the most common items found in geotechnical testing and research labs in its 38mm and 100mm diameter variants.

4.2.3 Simple Shear Apparatus

This is a complicated piece of apparatus that simulates the conditions of simple shear, and was first developed by Roscoe (1953) at Cambridge University.

This type of test models the stresses induced by seismic loading fairly closely, and has been used to study the effect of liquifaction on fine grained material.

With this apparatus, as with the triaxial cell, data results from the direct measurement of the deformation and loading of the sample and so it is possible to plot the stress - strain relationship directly in order to determine the damping and shear modulus.

There is no limitation inherent in the method on the size of sample that can be tested, other than the need to construct a sufficiently large apparatus, and provide the associated large loads and energy input that such a device would require.

4.3 SUMMARY OF TESTING METHODS

In the past, the resonant column device using cylindrical samples subjected to torsional vibration, has been the most commonly used apparatus to establish the dynamic properties of clays and sands. However as already discussed, due to the variation of shear strain across a cylindrical specimen when torsionally excited, hollow specimens have generally been used. This allows the accurate determination of parameters for fine-grained material and clays, but not large grained material. This technique is not suitable for the testing of large grained particulate material since the thickness of the ring, of the hollow sample, needed adequately to model the material would re-introduce the problems of variable shear strain that the technique was established to avoid and lead to a very large diameter.

The triaxial apparatus was selected as the most suitable compromise between the requirements for testing large samples and for providing realistic loading conditions, considering both the cost and time constraints of developing a new piece of testing equipment. Further, the development of a large scale triaxial cell capable of testing large particulate material would enable direct comparison with similar tests carried out on the 38mm and 100mm diameter cells already in use, in order to assess the effect of scaling and gradation on the response of the specimens. This could then lead to the development of tests that can be run on modified 38mm and 100mm samples allowing the determination of the properties of graded samples as previously outlined, whereby the material as a whole can be taken into account and not just the fines content.

The use of the triaxial apparatus for the determination of dynamic characteristics is hindered by the difficulties of making reliable measurements at very low strains of the order of 10^{-6}. If this can be overcome, then valid results can be achieved which compare very favourably with other devices, as demonstrated by Kokusho (1980) on small diameter samples. Both Seed et al (1986) and Kokusho (1981) used large triaxial cells to provide the only as yet published data on the dynamic shear modulus and damping for large particulate material.

Triaxial cells (up to ≃ 150mm) have also been used with success by Brown and Snaith (1974), Hicks (1970), Boyce (1976) and others in the determination of the response of road base material subjected to long term cyclic loading conditions.

PART II

Development of experimental apparatus and requirements of data monitoring system

5.0 EQUIPMENT DESIGN AND MODIFICATION

At the start of this project the facilities available were limited to the normal teaching requirements of the department, with the addition of some 100mm stress path cells. Specialist equipment was thus required to enable this program to be undertaken.

The standard equipment consisted of a number of static 38mm and 100mm triaxial cells. These were loaded either using geared electric motors, giving strain controlled tests, or from a constant pressure system, giving stress controlled tests.

In terms of the requirements of the testing program there was a need to develop a large triaxial cell capable of containing samples of large grained particulate material, and to enable the dynamic loading of both the large cell and the existing 38mm and 100mm cells.

New laboratory facilities were expected to be provided within an appropriate timescale and the large cell was designed to make use of these new facilities, including digitally controlled fatigue rated loading jacks. The design of the large scale cell is detailed in section 5.1.

In order to proceed with the testing of smaller grained material, work was undertaken to modify the existing static loading facilities to enable dynamic loading of the 38mm and 100mm cells. This work is detailed in section 5.2.

5.1 DESIGN OF LARGE TRIAXIAL CELL

The design, manufacture, calibration and operation of a large triaxial cell was integral to the objectives of this program. The design was however constrained within tight financial and manufacturing limits.

Loading would be provided by external hydraulic actuators under either manual or digital control. This would allow for a wide range of loading ranges, and ensure the versatility of the system. The triaxial cell itself could therefore be kept relatively simple, and the manufacturing costs and time kept to a minimum.

As part of the program of testing was to determine the effect of scaling on the sample response by comparing the results of tests carried out on the existing 38mm and 100mm diameter cells with tests conducted on the large cell, it seemed sensible to maintain the same ratio of sample sizes. This determined the expected sample diameter to be tested within the cell to 264mm

(≃ 10.5"), which tallied favourably with the particle size of the materials expected to be tested. Material available for testing had an upper size range between 20mm - 30mm, which would require minimum sample diameters of the order of 254mm - 305mm, obviously the larger the better, in order to allow reasonable stress distribution within the sample.

There was a physical limitation on the manufacturing side due to the manufacturer's inability to turn metal above a particular size. Allied to this were limitations on the length of elements that could be turned within the diameter limitations. This latter constraint could be overcome to some extent by the manufacture of special tooling, that could hold elements within the over-all diameter limitations of the lathe.

The nature of the loading jacks, the need to keep the design as simple as possible, and the requirement to ensure the versatility of the apparatus, meant that the loading ram had to be placed through the top of the cell. This necessitated careful design of the bush arrangement through which the loading ram would pass, and tight tolerances on the shaft - bore arrangement, in order to ensure there would be no pressure loss from within the cell. The friction on the loading ram / top cap interface had be kept to a minimum to ensure the

smooth operation of the cell. Further, in the case of dynamic testing the loading ram must operate equally well in both directions. This latter requirement has a bearing on the type of seals that can be used within the bush arrangement to ensure no pressure loss.
The final arrangement utilised a sealed bush in the top cap of the triaxial cell which incorporated PTFE bearing surfaces to reduce friction to a minimum.

Due to the tight tolerances on the bush arrangement, deformations of the top cap of the cell had to be kept very low, otherwise the running fit of the loading ram would have been impaired. The stiffness of the top cap was simply related to its thickness, which at overall diameters approaching 0.5m starts to have serious weight considerations.

The maximum size of sample that could be accommodated within the cell was restricted to 305mm (12") diameter. The need to ensure sufficent space around the sample for instumentation, and to allow deformation of the sample, coupled with the limitation of a maximum overall diameter for the cell of 457mm (18") (due to manufacturing constraints), meant there was no room within the cell for supports for the top cap. This meant that the pressure wall of the cell would have to support the top cap, resist the internal pressure, and carry the prestress applied between the top cap and base plate to seal the connections with the pressure wall.

Traditional triaxial cells use pressure walls formed out of tubes of perspex, which can be reinforced if required. These have the advantage of being translucent and thus allow visual inspection of the sample throughout the test. The internal diameter required for this large cell, coupled with the internal pressure and vertical loading requirements, ruled out the use of perspex since the required thickness would be too great. Stainless steel was therefore selected for the pressure cylinder, and in order to keep fabrication costs down, standard tubing of an appropriate diameter was found to be adequate. The ends of the tube were machined and a groove cut to allow for an 'O' ring seal between the cylinder and both the top cap and base plate. Appropriate grooves were machined into the top cap and base plate to accept the pressure cylinder.

Due to friction between the sample and the top and bottom plattens standard triaxial cells normally make use of samples with a height to diameter ratio of 2:1, in order to achieve a realistic failure mode within the sample. With sample diameters upto 305mm, this would require sample hieghts of 610mm. The higher the sample, the taller the pressure cylinder would need to be and bearing in mind the limited thickness of standard tubing, the more likely that buckling failure might occur. At these sample heights the overall length of the tubing exceeded the tooling capacity of the manufacturer. Also, the taller the sample the greater the difficulty in preparing the sample, since the preparation of granular samples requires the use of formers and vacuums in order to ensure their stability prior to the application of the confining stress (i.e. the cell pressure). This situation is further complicated by the loading arrangement of the hydraulic jacks which require the cell and sample to be assembled and then moved under the loading frame manually. The taller the sample the more susceptible it would be to diaturbance by such movement prior to the testing. For these reasons it was decided to limit the height of the cell and use samples with height to diameter ratios near to 1:1. This necessitates the use of friction free end plattens in order to limit the effect of end constraints on the sample deformation. These friction free end plattens will be discussed in greater detail later.

Due to the restricted size of the apparatus, the whole assembly needed to be dismantled in order to prepare the sample within the cylinder. For this reason and to ease manufacture, all connections utilised screw threads (mostly stainless steel cap screws) with high strength steel tie studs being used between the top cap and base plate to prestress the whole apparatus and thus seal all joints between the external elements. Two cylindrical steel rings distribute the load from the eight tie rods evenly around the top and bottom plates. Drainage and pressure lines with appropriate fitments for the laboratory were provided within the base plate with appropriate detailing to the top and bottom plattens, allowing the full range of drained and undrained tests to be performed on dry, partially saturated, and saturated materials.

Sealed access points, similar to those employed on the Imperial College stress path cells were incoporated in the base plate and top cap, which allowed wiring etc from any sensors placed within the cell to be connected to recording apparatus external to the cell.

An essential safety device provided on the top cap was a pressure release valve set to relieve any excess pressure induced within the cell as a result of say, a sudden collapse of the specimen followed by the rapid insertion of the loading ram. The setting of the valve needs to be well below the design limit for the cell.

As the pressurising medium was water all internal elements were made from stainless steel, except the top sample platten, which for lightness, was made from aluminium. This helped on a number of counts; ease of assembly, to minimise disturbance to and dead weight upon the sample upon formation. To reduce costs the external elements utilised mild steel in various grades.

Due to the large size of the cell, and weight of the individual elements, the dismantling and assembly of the cell at the beginning and end of each test required the use of lifting devices, with precise handling control, which is necessary when positioning the top cap. The whole apparatus was positioned on a greased track placed beneath the loading frame which allowed easy smooth movement of the cell in order to allow sample preparation, assembly and dismantling adjacent to the loading frame.

A diagramatic view of the cell is shown in figure 5.1, and views of the actual apparatus are shown in plates 5.1 to 5.5. Detailed specifications and design methods are given in appendix 1.

The cell was satifactorily pressure tested to 4137 kN/m^2 (600 psi) , and for the tests carried out for this thesis the pressure release valve was set at 1379 kN/m^2 (200 psi).

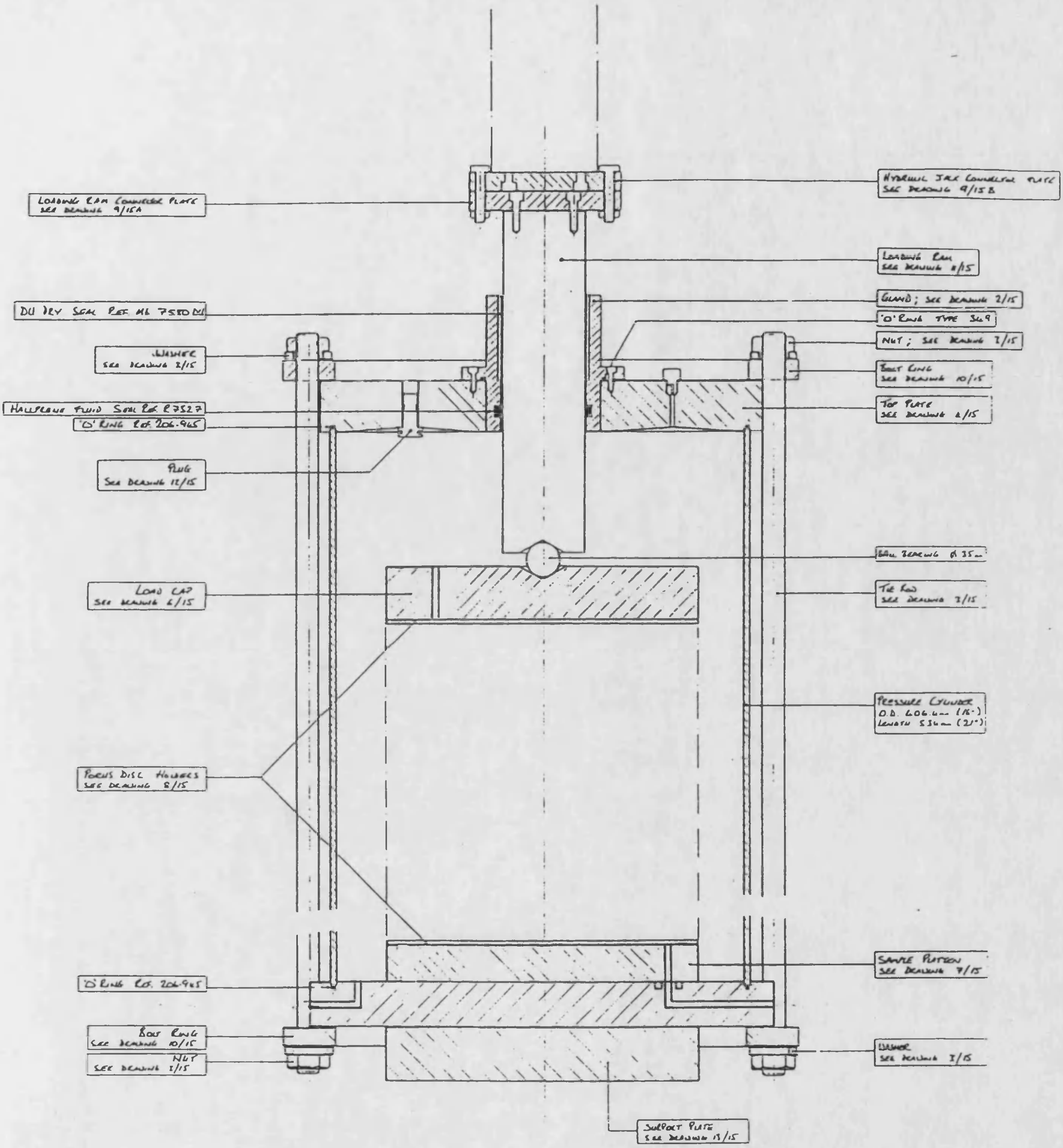


Figure 5.1. Detail of large triaxial cell.

5.2 MODIFICATION OF STATIC LOADING FACILITIES

The original loading equipment was only capable of applying static loads and consisted of geared electric motors and a constant pressure system. The constant pressure system operated off an air line via a pressure regulator, which, via an enclosed air bladder/water interface provided either a constant air pressure or constant water pressure. The regulator was manually operated and it was hoped that by conecting a stepper motor controlled by a computer to the regulator the system could be used to provide variable loads. The control and feedback system had to be designed and built from scratch. The standard and modified systems are shown in figures 5.2 and 5.3 respectivly. It was found that due to the air/water interface and the flexible nylon pipework the system was not 'stiff' enough, in that pulsing was set up within the pipework. This resulted in a loss of sensitivity and control since the system became unstable and could not respond in an appropriate manner for the feedback loop to function correctly. See appendix 2 for details of this system.

Full hydraulic systems are more appropriate to the application of this technique. The new laboratory facilities would include suitable loading frames for the dynamic tests, and by this stage of the project these

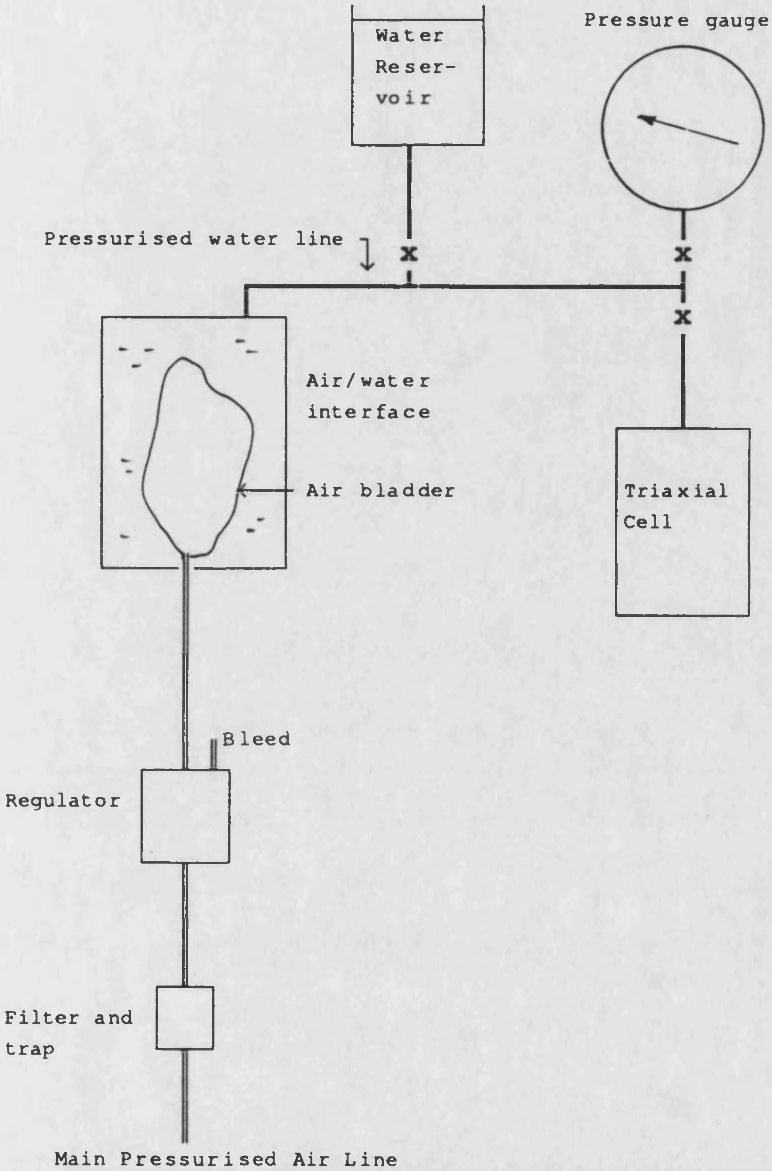


Figure 5.2. Standard pressurising system

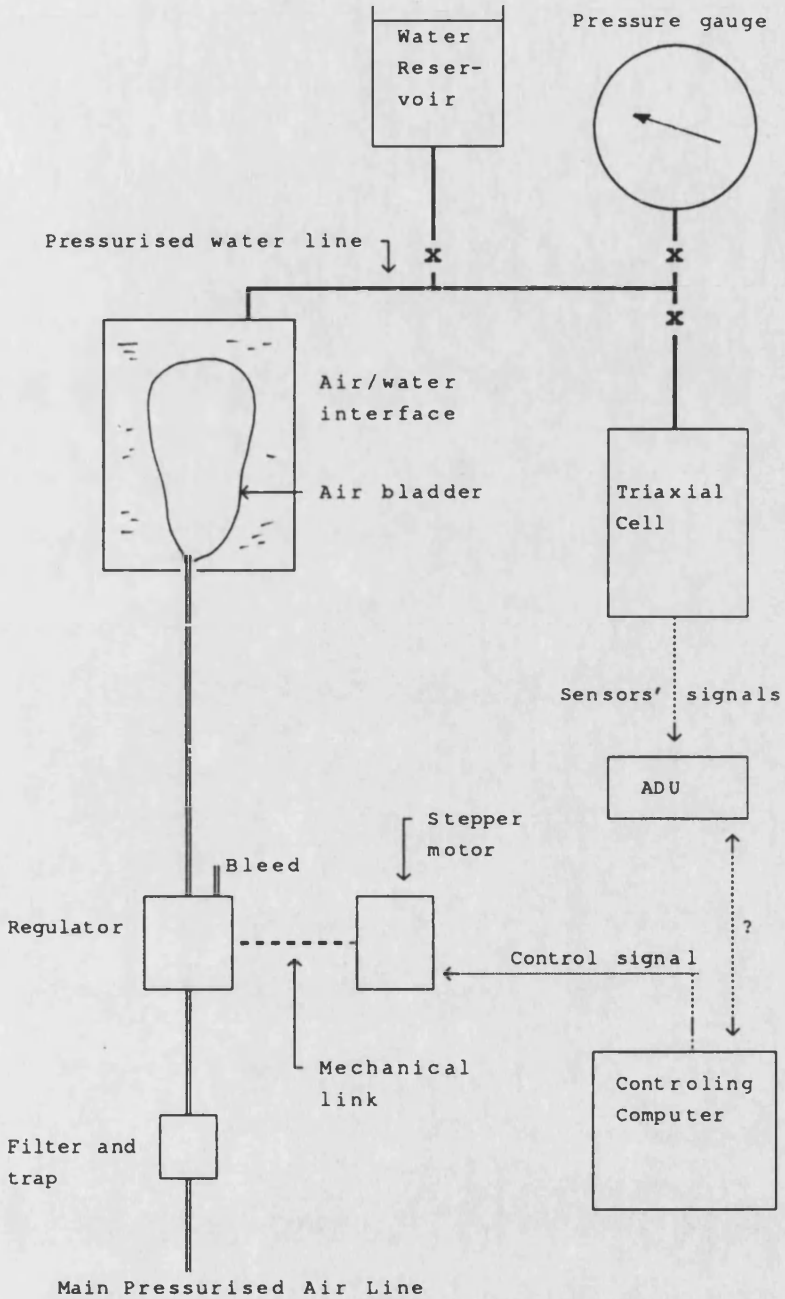


Figure 5.3. Modified dynamic pressurising system

laboratories were expected to be operational within a sufficently short period of time to make the expenditure necessary to adapt the air/water system to a hydraulic system uneconomic.

The dynamic loading arrangement for the 38mm and 100mm triaxial cells was thus to utilise the DARTEC 100kN loading frame using a digital control system.

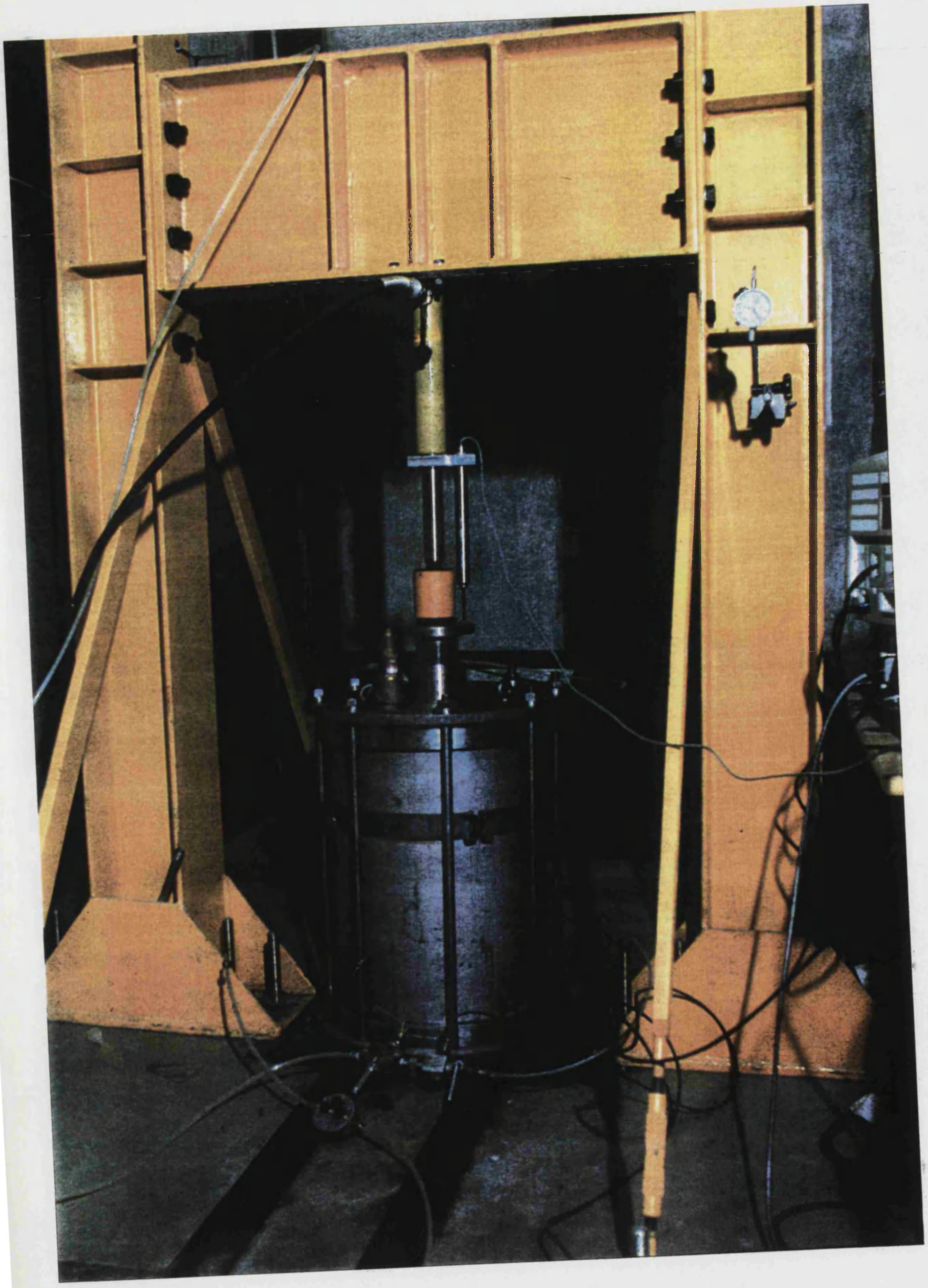


Plate 5.1. Cell assembled in the static loading configuration.

Plate 5.2. Free standing sample sealed around top and bottom plattens. Top drainage fitting also shown.

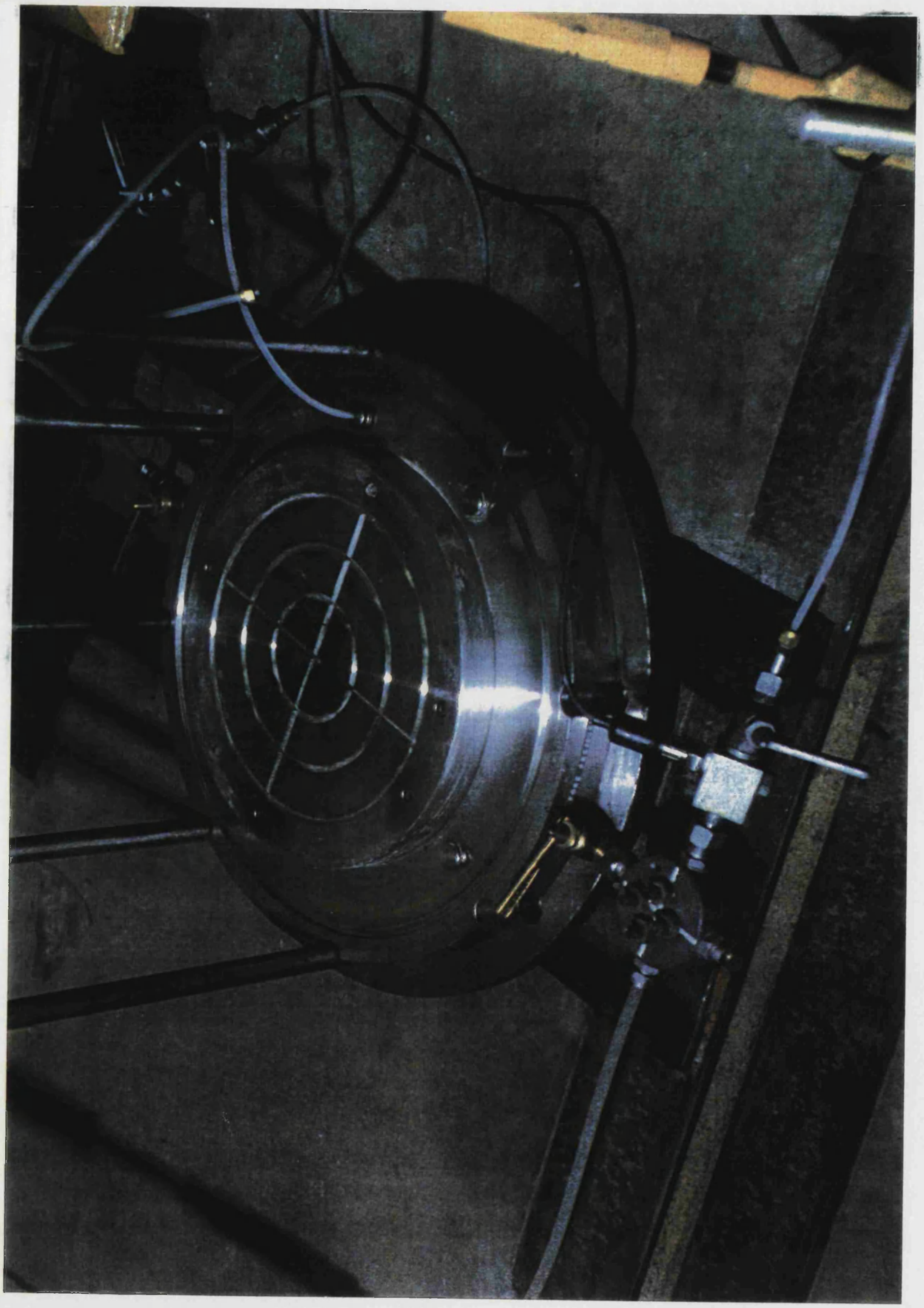


Plate 5.3. Base of cell.

Plate 5.4. Underside of top platten.

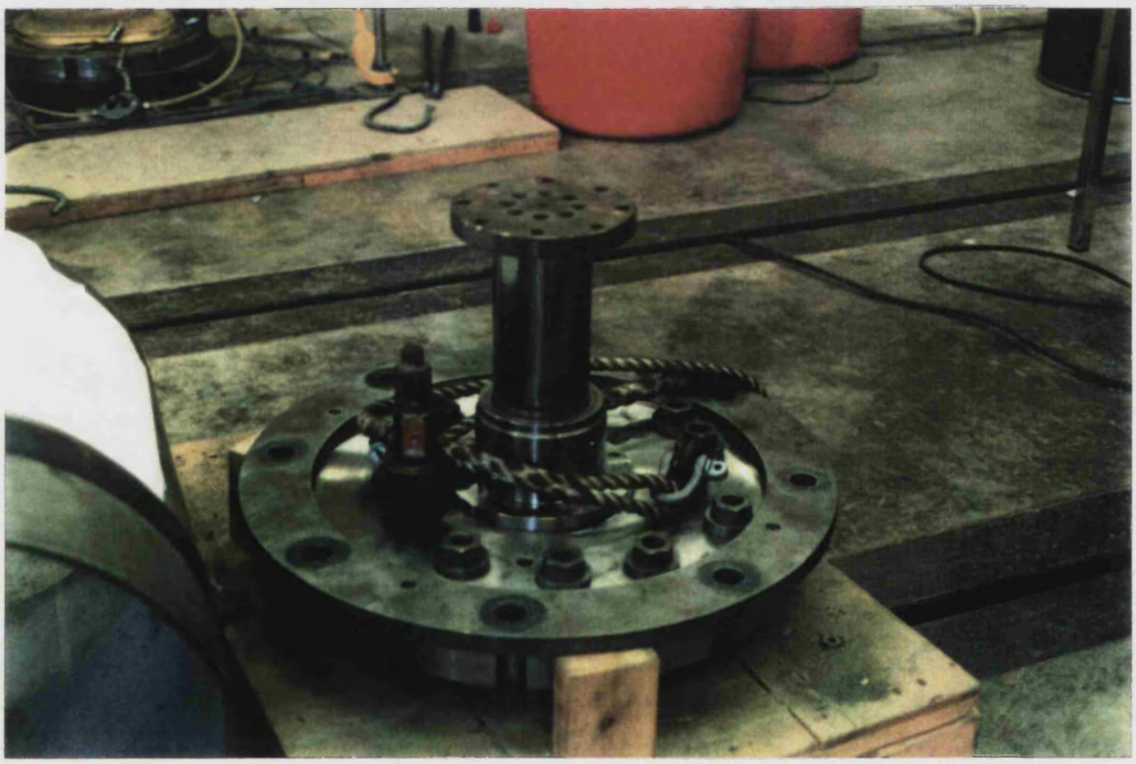


Plate 5.5. Top of cell.

6.0 OPERATING PROCEDURES

This chapter examines the data required in order to abstract the necessary information from the tests and the methods employed to establish this data. Further, techniques and procedures specific to the apparatus and testing methods used will be discussed.

The tests for this study were essentially comparative in nature to determine the damping and shear response of granular samples. Since the extraction of the required data and determination of influencing factors such as gradation and angularity was expected to be difficult to start with, it was felt sensible to limit other factors that might mask these effects. The tests were therefore run dry, removing the need to consider scaling of pore water effects, which might give rise to liquifaction problems in the fine grained samples during the calibration phase, and alleviate difficulties involved with determining pore water pressures. The sample preperation procedure would also be simplified, as factors associated with creating a sample with a uniform porosity would be avoided. This factor can dramatically complicate the formation of samples, especially at higher densities, which can otherwise utilise relatively straight forward techniques, such as the tamping of layers of material.

6.1 VARIABLES TO BE MEASURED

In order to produce values of shear stress and shear strain from triaxial tests, the following factors need to be monitored throughout the test procedure -

major principal stress
minor principal stress
axial strain
radial strain

From these , the shear stress and shear strain can be determined, and hence the shear modulus and damping ratio.

6.1.1 Major Principal Stress

This is determined from the axial load applied and the cross-sectional area of the sample within the cell. The axial load for dynamic tests is usually continuously monitored by load cells, and recorded in an appropriate manner.

In order to neglect the effect of friction between the loading ram and bush interface, the load cell can be placed within the triaxial cell , either on the cell base beneath the sample, or on the end of the loading ram above the load platten.

6.1.2 Minor Principal Stress

This is easily established by monitoring the medium used to pressurise the triaxial cell. If static cell pressures are used, then a standard pointer gauge may be adequate. Otherwise a pressure transducer connected to a datalogger can be used continuously to monitor and record the cell pressure. Under dynamic loading the cell pressure may not be constant even if it is meant to be. This is due to a possible time lag for the pressurising system to respond to the sample deformation.

6.1.3 Axial Strain

In standard static triaxial testing, it is common to measure the axial deformation of the sample by monitoring the external movement of the loading ram. However, using optical trackers sighted on to targets attached directly to the soil sample to record the compression of large diameter specimens of granular material, Moore et al (1969) showed that at very low strains, the movement of the loading ram did not represent the true compression of the sample. The relative motion of the loading plattens was also shown to over-estimate the vertical strain. These disparities are caused by strains resulting from the seating of the loading rod, top plate and specimen ends. Moore et al also noted that direct measurement using strain gauges attached to the sample underestimated the vertical strain. This was attributed to the reinforcement effect of the foil gauges on the specimen in the region of their attachment.

The need to measure small strains accurately during dynamic tests has led most researchers to devise means of measuring the vertical strains by recording the relative movement of points located on the sample itself.

Hicks (1970) located transducers around the sample, secured by springs. However as well as constraining the sample, this arrangment allows the transducers to slip on the surface of the membrane

Brown and Snaith (1974) testing 150mm diameter samples of bitumen macadam secured locating targets to the side of the specimen with araldite. Perspex collars, split to allow lateral deformation and held together by springs, were placed around the specimen on the locating points. The action of the springs kept each collar located on the targets, with small pieces of rubber placed between the collars and the sample to prevent tilting. LVDT's were then secured between the collars to measure their relative displacement.

A system used by Boyce (1976) on 6" diameter specimens of large grained granular material was to secure locating studs into the side of the sample that projected through the rubber membrane to which LVDT's were attached to measure the relative displacement between two studs in the vertical plane.

Jardine, Symes and Burland (1984) reported on the use of electrolytic levels to measure the axial displacement over a central gauge length on 38mm diameter samples of sands and clays. The devices described could resolve to less than 1μm over a range of 15mm. The principle of operation is that a hinged arrangement converts displacements between two footings mounted on the sample into a rotation of a capsule containing an electrolyte and electrodes. The resulting signal gives a measure of the rotation of the capsule, and with knowledge of the spacing of the footings the axial displacement can be calculated. Whilst these instruments appear to give good response during static tests, their use for cyclic loading would need to be examined. The reversing of the loading would be expected to set up oscillations within the fluid of the transducer giving the probability of erroneous results.

Kokusho (1980) used a highly sensitive "gap sensor" consisting of pairs of electromagnetic discs which were sensitive to relative movement. These were situated above the top platten within the cell and could reportedly detect strains as low as 10^{-6}.

6.1.4 Radial Strain

The accurate measurement of radial strain is a particular problem as one needs to record the expansion/contraction of the sample diameter without constraining the material significantly

Brown and Snaith (1974) described the use of hinged perspex collars secured on to targets located on the surface of the spacimen, and held together by a spring. As the sample diameter changed, so did the gap between the free ends of the collar, and this was measured by an LVDT.

Boyce (1976) used flexible strain gauged rings to measure the radial strain on 150mm diameter specimens of granular material. These rings were attached to two diametrically opposed locating studs secured into the sides of the specimen. An increase or decrease between the attachment points flexes the rings into an oval shape which is detected by strain gauges bonded to the ring surface. The rings were manufactured from a casting araldite and made narrower at the strain gauges to give a better deflected shape and increased sensitivity.

6.2 METHODS OF MEASUREMENT ADOPTED

The various methods used in this study to determine the response of specimens tested differed, depending on which size cell was used and whether the loading was static or cyclic.

6.2.1 38mm and 100mm Triaxial Cells

On the 38mm and 100mm static tests using the standard triaxial cells, proving rings were used to determine the load on the sample. These were strain controlled tests and thus the axial deformation of the sample was a function of time, but was also determined with a dial gauge. The cell pressure was provided by pressurised water via an air/water constant pressure system, as described in section 5.2, and was measured using a standard analogue gauge.

For the dynamic tests, the cells were placed within a digitally contolled 100kN fatigue frame, and the load and stroke determined via the frame sensors.

6.2.2 Large Cell

Static cell pressures were provided using a similar air/water constant pressure system as utilised for the smaller cells, and measured in the same way, bearing in mind the comments made in section 6.1.2.

When the static hand operated hydraulic jacks were used for the static calibration tests the load was measured using appropriate external load cells, and the axial deformation determined by strain gauge displacement transducers monitoring the movement of the ram.
When the digitally controlled jack was used for the dynamic tests the external stroke and load could be monitored using the in-built load cell and Linear Variable Displacement Transformer (LVDT). Unfortunatly, lack of resources prevented the purchase of an internal waterproof load cell, and thus careful determination of the frictional effect of the bush/load ram arrangement was necessary. This will be dealt with later.

As already noted, in order to assess the true response of the sample to low strain levels the 'on sample' axial and radial deformation was required. The use of the electrolytic level type transducer was considered, but they were not available. The axial deformation was therefore, also established using waterproofed LVDT's placed inside the cell. These were positioned to measure the relative movement, in the vertical plane, between location studs secured to the sample. These location studs are descibed in section 6.2.2.1. Each LVDT was secured to the lower location stud and a lipped target element screwed onto the upper stud, so that the LVDT spindle could not slip. The waterproof trunking, secured to the base fittings of the cell, containing the electrical wiring of the LVDT was utilised to carry the self weight of the transducer, thus keeping the weight off the sample. This trunking was coiled in a loop to allow sufficient flexibility to the arrangement for location purposes, and also to provide for the unrestrained deformation of the sample whilst loaded. This arrangement is illustrated in plate 6.1.

In order to determine the radial deformation it was hoped to use non-contacting displacement transducers sighted onto targets attached to the sample. These types of transducer utilise the inductive technique which allows highly sensitive displacement measurement. The major advantages of this system are that the technique does not impose any constraint on the sample, and the system will 'stand alone', in that all the signal conditioning is self contained giving a linear and repeatable, within certain limits, analogue signal that can be recorded directly. Further, the system is robust within the testing environment. Cost constraints eventually ruled out the use of this method. Since much time and effort was expended on this system, the principal details are contained in Appendix 3.

It was therefore decided to use radial strain rings similar to those utilised by Boyce (1976) made from casting araldite. This necessitated the development of the necessary tooling and skills, and is detailed in the following section.

6.2.2.1 Radial Strain Rings & Location Studs

The strain rings work on the principle of placing a strain gauged flexible ring around the sample on two diametrically opposed locating studs secured to the sample, any expansion/contraction of the sample flexes the strain ring, which can be monitored via the strain gauges, see plate 6.2.

The strain rings were manufactured from a casting araldite which consists of two components, resin and hardener. A variety of resin/hardener combinations, as well as other components such as mineral fillers, are available to produce finished materials with particular properties and workability. The main industrial useage of these products is within the electronics industry and the material properties are generally directed to that field. The combination of resin/hardener considered most appropriate to the strain ring application was epoxy resin CY 1302 GB, which was available in the appropriate quantities and included mineral fillers to reduce shrinkage and decrease the coefficent of expansion, and hardener HY 1300 GB. This combination had the most suitable thermal expansion coefficient, elasticity, strength, workability and reaction time.

The procedure for the manufacture of the strain rings was as follows.

1. Former prepared with cleaning agent.
2. Release agent QX11 applied to former. This release agent is based on carnuba wax. It is important that the release agent does not contain silicon, otherwise the strain gauges will not adhere to the strain rings.
3. Resin and hardener mixed in the ratio of 100:11.1 by weight or 100:19.5 by volume, taking care to minimise air bubbles within the mixture, and then...
4. poured into former whilst placed on a vibrating table/support so that air bubbles were forced to the surface.
5. Left to cure for 48 hours.
6. Removed from mould and checked for imperfections.
7. Rings placed in oven at 40°c for 28 days, to ensure material fully cured and material properties stable.

8. The rings were then placed in the digitally controlled 100kN frame and subjected to a series of displacement cycles.
9. Rings that survived stage (8) were then strain gauged, with each pair of gauges wired in a half bridge arrangement, and calibrated.

As the rings would be used immersed in water, the strain gauges, wiring and connections to the gauges had to be waterproof. This was achieved by selecting appropriate cabling and sealing the gauges and direct connections with a wax compound. Each individual strain ring was calibrated such that the readings from the strain gauges could be correlated to the expansion/contraction of the rings. Only those rings with repeatable calibration graphs could be used for the dynamic testing program. This calibration procedure is detailed in section 8.1.

In order that the strain rings could be located around the samples location studs were secured to the sides of the soil samples. These studs were also used to provide fixing points for the LVDT's measuring the axial deformation. These location studs are shown in figure 6.1 and plate 6.3, and consisted of two elemants which sandwiched the membrane providing a secure location position. It was important to ensure a watertight seal around the membrane, otherwise the cell water could enter the sample.

A hole was needed in the membrane at the position of each location stud where the two elements screwed together. In order to prevent tearing, the membrane was reinforced at these points with ordinary cyclist puncture repair material, and a hole was then punched through the resulting 'sandwich'.

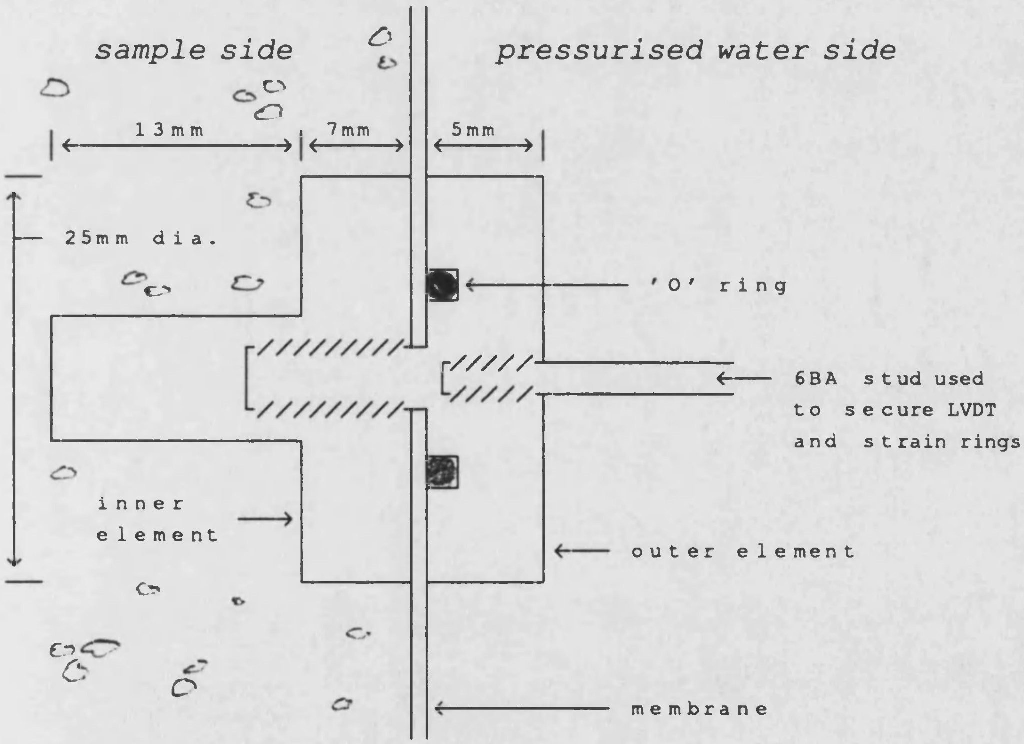


Figure 6.1. Details of location studs

6.3 FRICTION FREE END PLATTENS

Traditional triaxial cells use samples with a height to diameter ratio of 2:1. This is in order to ensure that a representative failure is achieved within the body of the sample, free from the end effects of the top and bottom plattens. It is the friction between the plattens and the ends of the sample that causes the characteristic barrelling of triaxial cell samples.

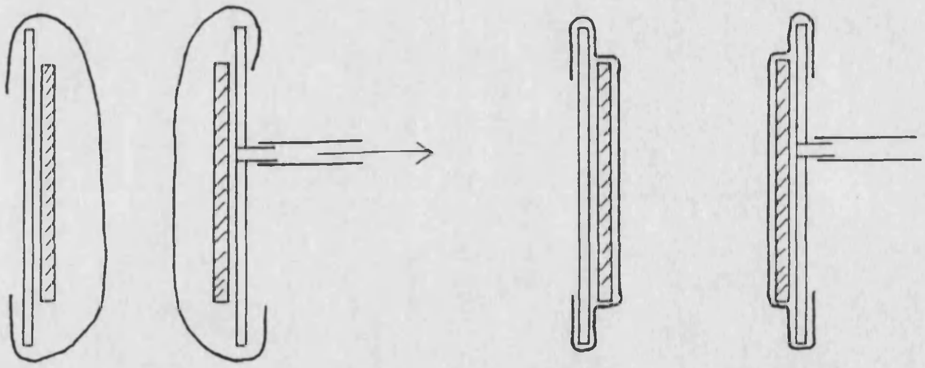
As discussed in section 5.1 due to a number of reasons the large cell was constructed with insufficent height to allow 2:1 ratios to be used for the larger sample diameters. At the larger diameters tested, ratios approaching 1:1 were used, necessitating the use of friction free end plattens in order to allow free movement of the sample on the end plattens.

Various arrangements were tried to achieve friction free ends. The most sucessful consisted of PTFE discs cut into segments placed between the sample and end plattens, plate 6.10 shows the placing of the upper 'free end'. One face of the PTFE was 'dimpled' and this face was placed towards the platten. Silicon grease could be placed between the PTFE and end platten to lubricate the assembly. Experiments with smooth face materials and various lubricants proved unsatisfactory since in such circumstances the lubricants acted more like glues preventing sliding. The 'dimples' reduced this problem. However, it should be noted that this solution did not prove to be entirley successful due to the use of an internal vacuum to form the free standing samples of granular material. This will be expanded upon in section 8.3.

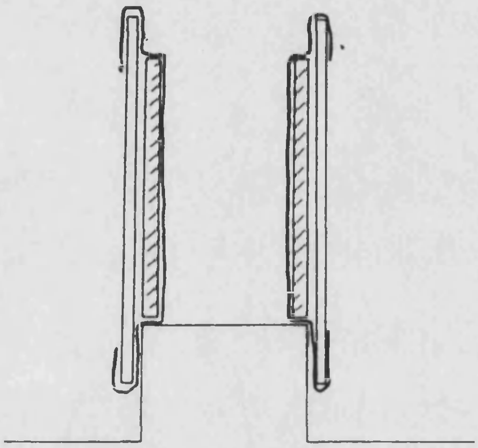
6.4 SAMPLE PREPARATION

The testing of granular material in triaxial cells requires the ability to prepare free standing samples of particulate material. This is achieved in the following manner.

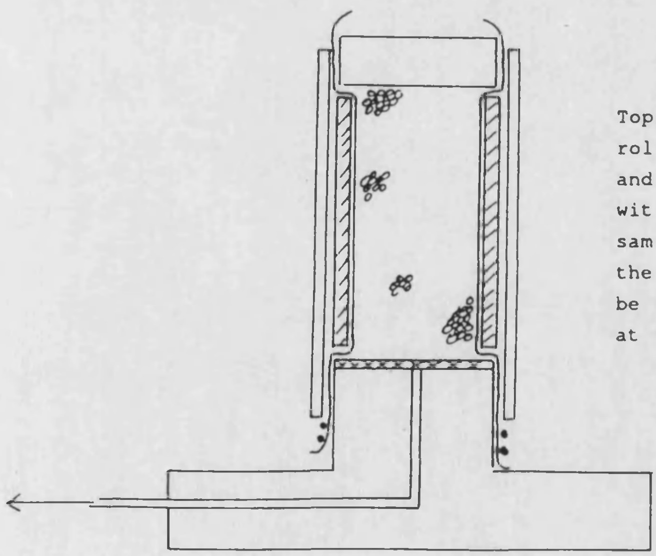
The membrane is first stretched within a metal former and a vacuum applied to pull the membrane flat against the inside of the former. The former with membrane attached is then placed over the bottom platten. The material that will constitute the sample is then placed within the former in an appropriate manner in order to achieve the correct density, this will be discussed later. Once all the material is appropriatly compacted the top cap/platten is placed on the top of the sample. The membrane is then rolled off the outside of the ends of the former and sealed around the top and bottom plattens with O rings. A vacuum is then applied to the



Membrane stretched over formers and vacuum applied to pull membrane flat against former to produce a flat surface.



Former assembly placed over base platten, ensuring any base fittings, eg. friction free end plattens or filters, are already in position. Sample material can then be placed within the former assembly.



Top platten inserted, and membrane rolled off top and bottom of former and sealed around top and base plattens with 'O' rings. Vacuum applied to sealed sample allowing removal of former. With the sample now free standing the cell can be assembled and the cell pressure applied, at which point the internal vacuum is released.

Figure 6.3. Sample preparation sequence

now air tight sample, which allows the former to be removed and the sample to remain free standing. The cell apparatus can then be assembled and the confining cell pressure applied at which point the internal vacuum can be released. This sequence is illustrated in figure 6.3, and plates 6.5 to 6.7 for the 100mm cell, and 6.8 to 6.11 for the large cell.

Each cell size used different formers and methods to apply the vacuum/suction pressures. The large cell used an inner and outer former. The outer was a split steel cylinder which fitted over the outside of the base platten, whilst the inner was a split wooden former that produced a nominal sample diameter of 254mm, and incorporated cutouts for the location studs so that a smooth sided sample could be produced. This inner former also allowed an even distribution of the vacuum to pull back the membrane. The use of lubricated end plattens meant that the base lubricated end had to be prepared prior to the placement of the former over the bottom platten, and at the top prior to the top platten. The vacuum was applied using an electric vacuum pump.The 38mm and 100mm cells used smaller sized metal outer formers and split plastic inners around which the membrane was stretched. Manual suction was sufficent to pull the membrane back against the formers, but the electric pump was used to evacuate the samples.

The various formers for each of the cells are shown in plate 6.12.

6.5 MEMBRANES

The membranes used in this study were made from latex rubber. Standard sizes existed for the 38mm and 100mm sample sizes, although these were more appropriate for use with clay samples and very fine sands. Care had to be taken when using larger grained material in order to avoid tearing. For the large cell special membranes had to be made. The standard material thickness, as used on the smaller cells, made to the required diameter was suitable for fine grained material, but was punctured by the larger particles. The thicker the membrane, the more resistent to tearing, however it also provides more restraint to sample deformation so influencing the material response. Tests with a selection of different membrane thicknessess at various cell pressures enabled 'appropriate' membranes to be selected. Problems were encountered during the testing due to membrane failures. These membranes deteriorate over time, as well as with use, and are very susceptible to sunlight. As will be discussed later, it was found necessary to utilise additional protection to prevent the membranes being punctured by the angular material used in this study at high cell pressures.

An illustration of the different membranes is given by plate 6.12.

6.5.1 Membrane Corrections

As mentioned in section 6.5 the membrane will provide some restraint to the sample. This can be accounted for by considering the nature of the sample deformation and the stiffness of the membrane. The nature of sample deformation is traditionally considered as either plastic, barrel type failure, or brittle, where a defined slip plane develops prior to failure.

For plastic type failure a correction factor may be calculated using an equation proposed by Henkel and Gilbert (1952), which in terms of kN/m^2 units is given below

$$C_m = \frac{0.4.M.\varepsilon.(100-\varepsilon)}{D} \qquad [6.1]$$

where

C_m = membrane correction, units kN/m^2.

M = Modulus of membrane material, units MN/mm width, as determined from extension tests on samples of the membrane material.

ε = axial strain of sample, units %.

D = Initial diameter of sample, units mm.

However, more recent research - Wesley (1975), Sandroni (1977), Gens (1982) - has indicated that this equation overestimates the correction to a varying degree. Wesley concluded that the correction factor depended on the deviator stress, but was unlikely to be more than 3% of the peak value. Gens proposed that no correction was required at all. Sandroni produced his results in the form of graphs, indicating that for a 38mm sample with a membrane 0.2mm thick, the correction factor would be a maximum of $2kN/m^2$ at 20% strain. Factors for other diameter samples and/or membrane thicknesses could be acertained by multiplication by the following;

$$\frac{38}{D} \times \frac{t}{0.2}$$

where

D = sample diameter [mm]

t = membrane thickness [mm]

With sample diameters of 254mm, as used in this program, any correcting factors thus determined become negligible.

The correction for the brittle type failure is generally given in graphical form, and is again dependent on factors such as sample diameter, membrane stiffness and axial strain. The correction values for the brittle type failure are generally greater than for the plastic type failure. However in both cases, unless the membrane offers excessive resistance, the effect is small when dealing with high strength materials. Also, as the size of sample increases the effect is reduced, as can be deduced from equation 6.1.

A further membrane effect that needs to be mentioned is that due to the indentation of the membrane around the surface of the sample due to the confining pressure. This has the effect of reducing the volume of the sample and can influence volume change measurements. It is of most concern during undrained saturated tests where any volume change of the sample may affect the pore water pressure measurements. Obviously this factor will be influenced by the particle size and grading of the sample, being greatest for single sized large grained particulate material.

Plate 6.1 LVDT fixed in position between two location studs.

Plate 6.2 Strain Rings positioned around the sample.

Plate 6.3a Close up of location stud and fixing for strain rings.

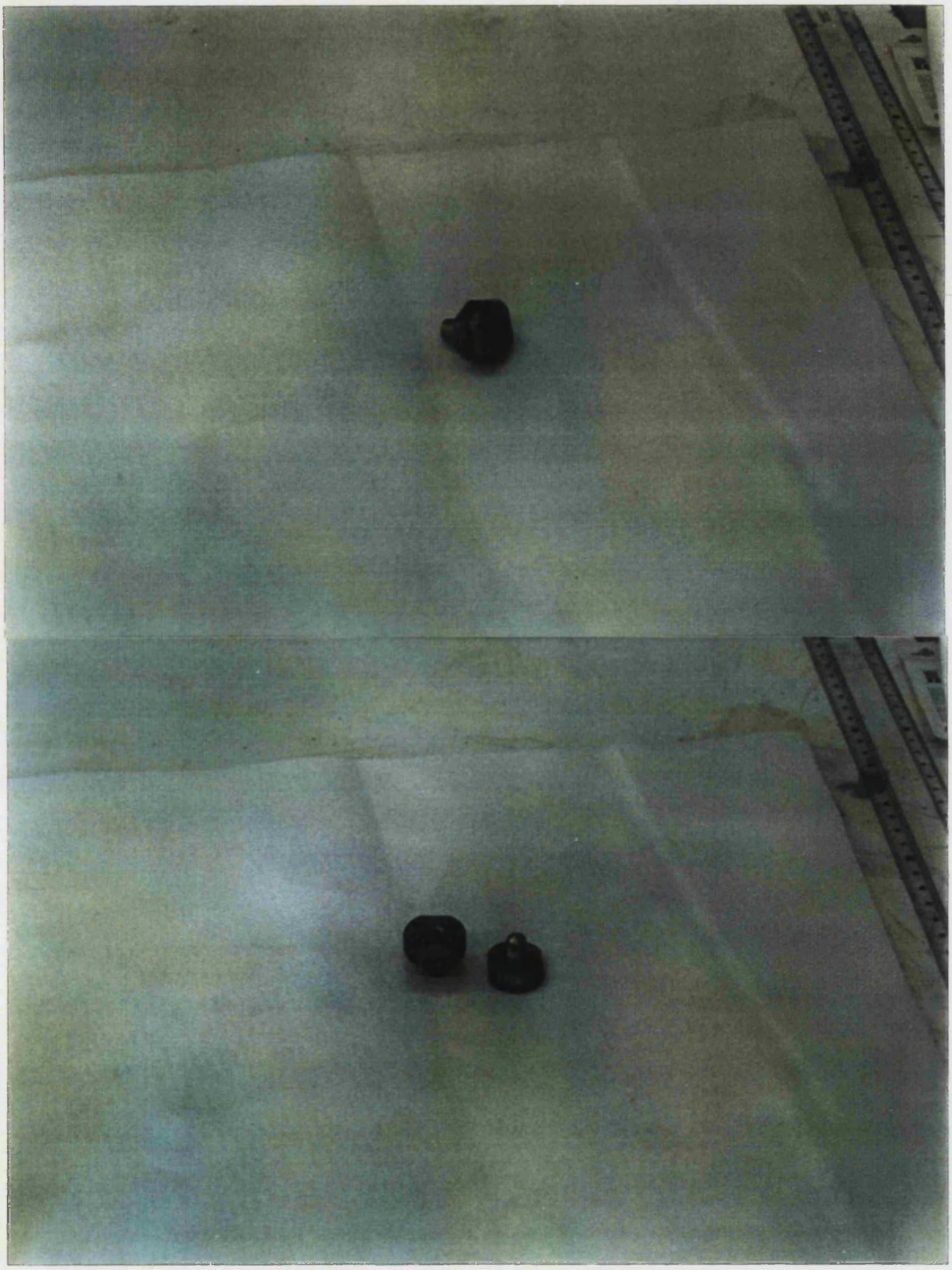


Plate 6.3b Location stud in more detail.

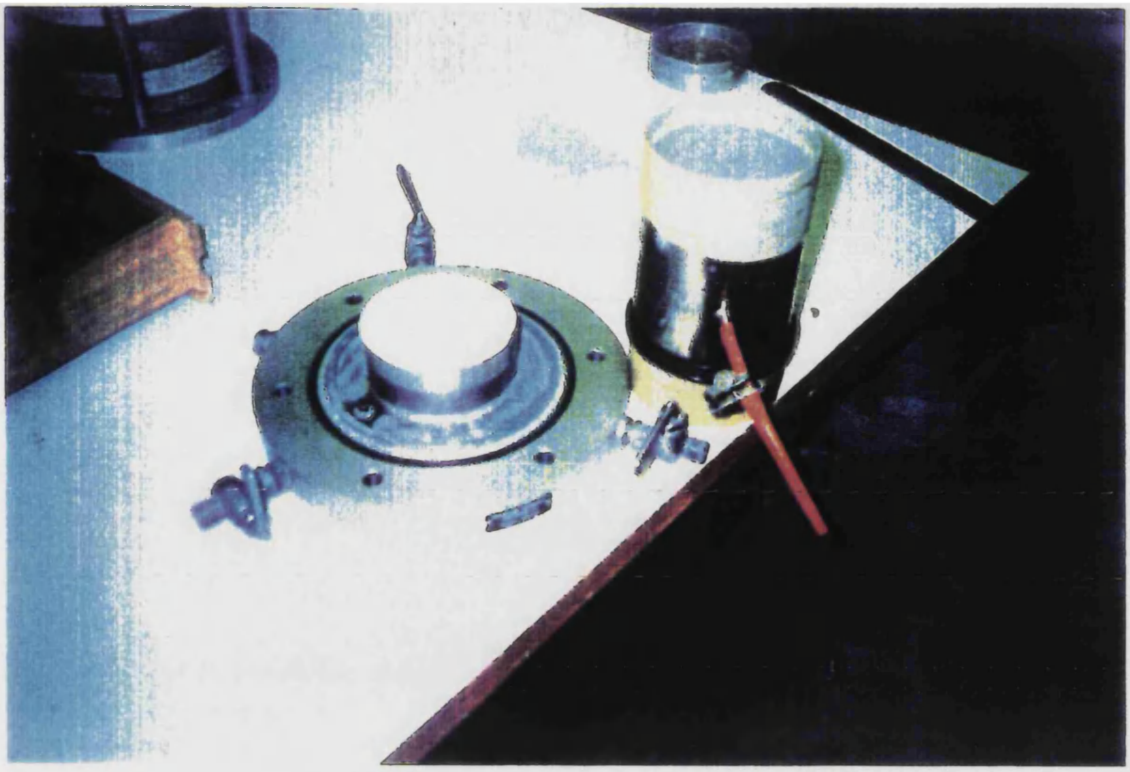


Plate 6.4 100mm sample preparation sequence. Base plate and former with membrane held back by vacuum.

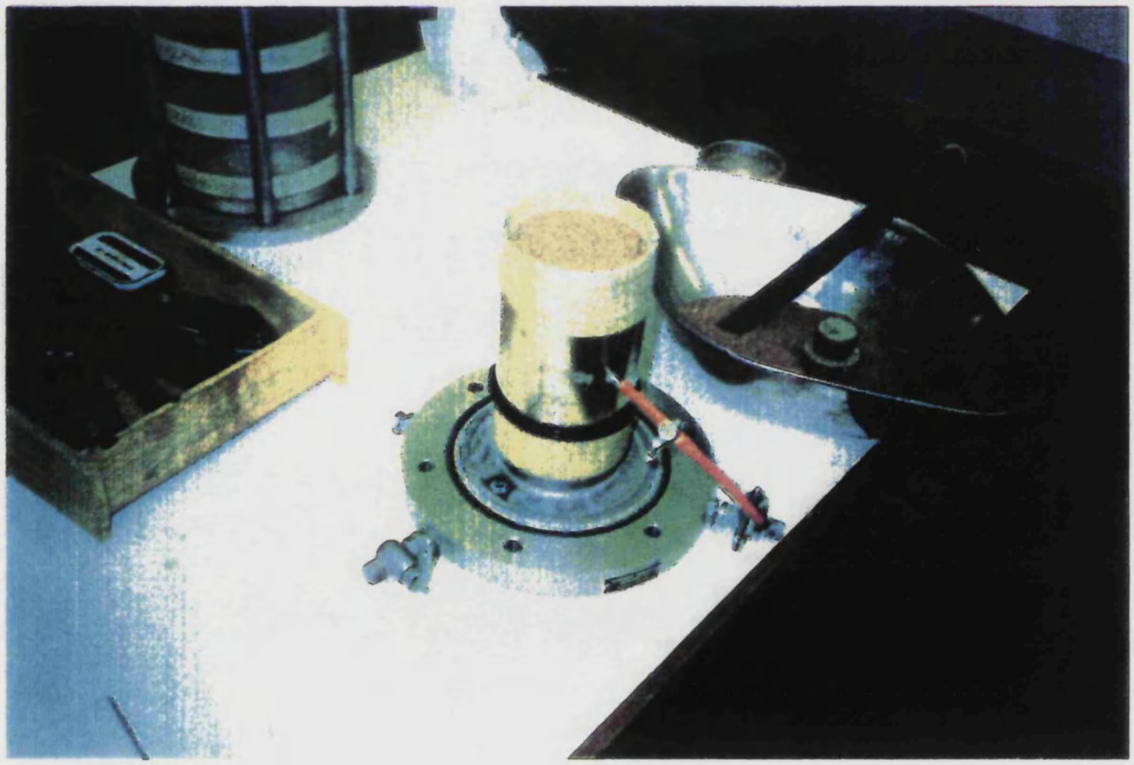


Plate 6.5 100mm sample preparation sequence. Sample material placed in former on base plate.

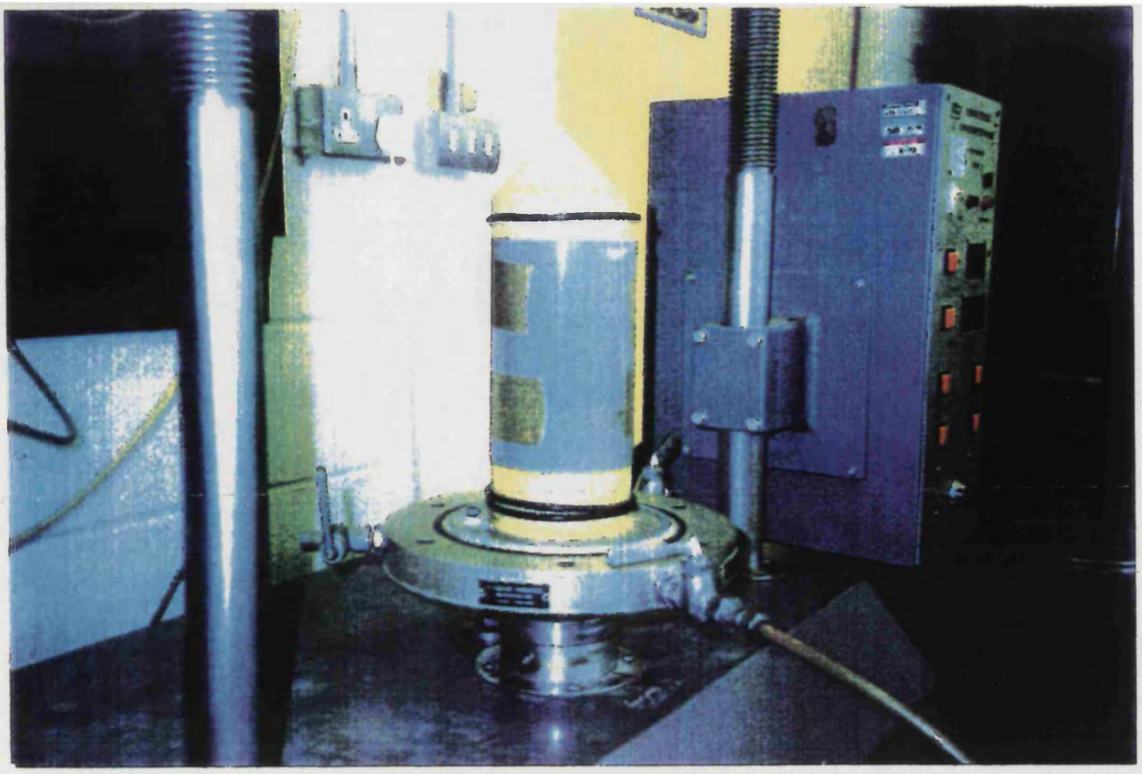


Plate 6.6 100mm sample preparation sequence. Top platten placed in position and membrane sealed to top and bottom plattens. Vacuum applied to sample.

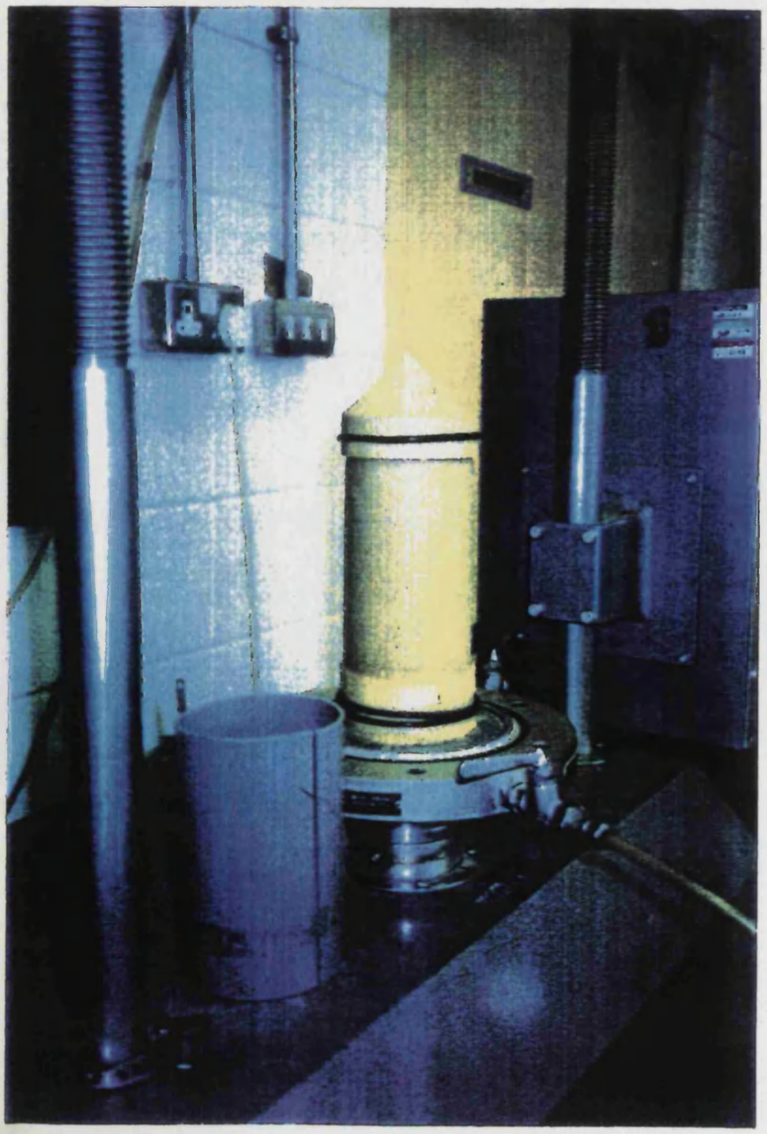


Plate 6.7 100mm sample preparation sequence. Former removed, and sample free standing prior to cell assembly.

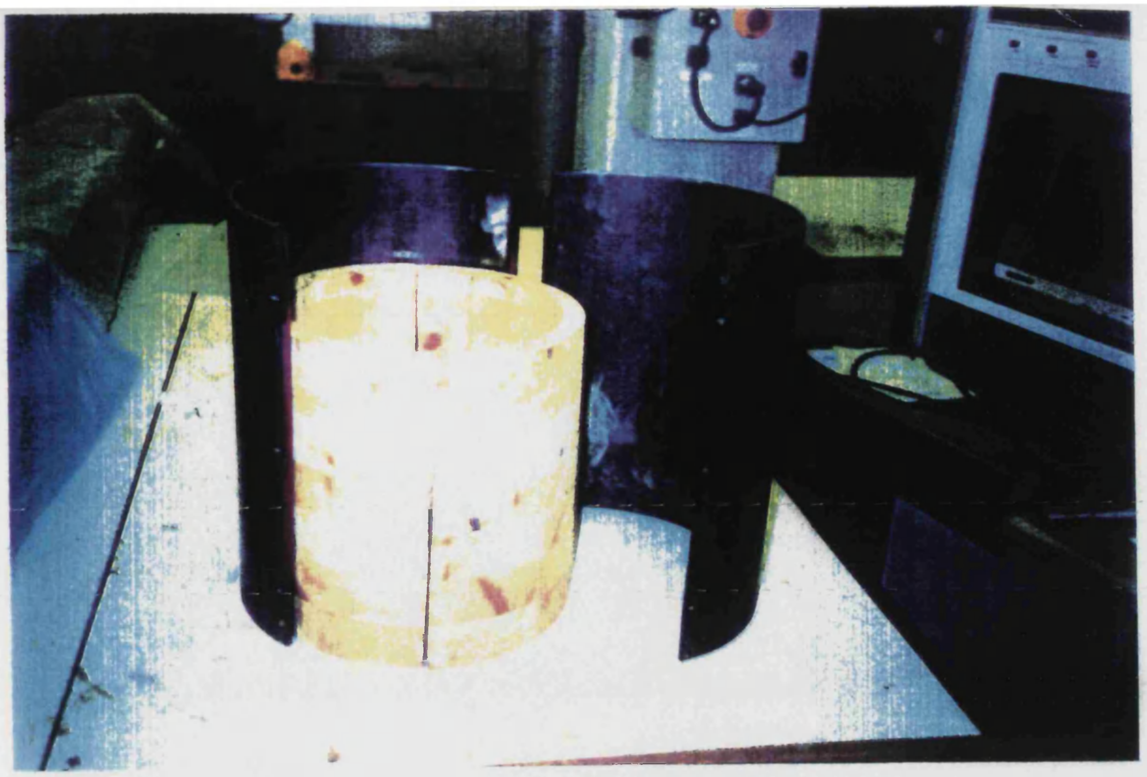


Plate 6.8 254mm sample preparation sequence. Internal and external formers.

Plate 6.9 254mm sample preparation sequence. Formers placed over base platten with membrane held back by vacuum.

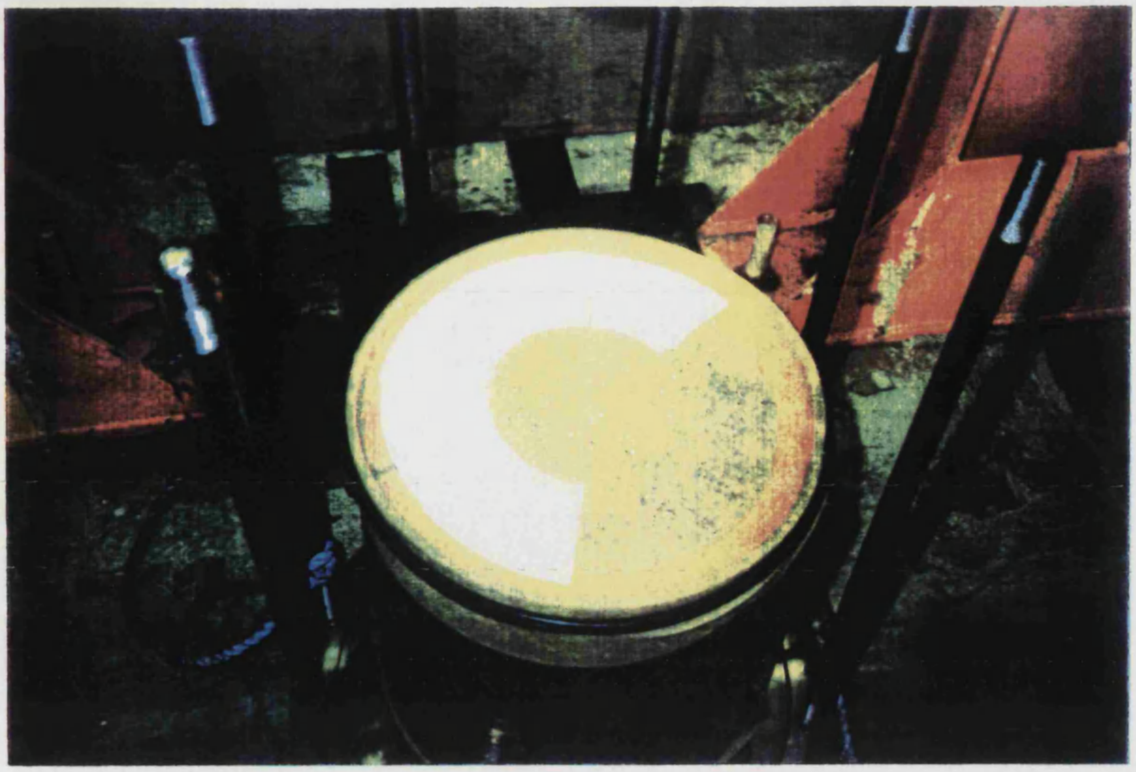


Plate 6.10 254mm sample preparation sequence. Material placed within formers, and friction free top platten being positioned.

Plate 6.11 254mm sample preparation sequence. Free standing sample with top platten in position and mambrane sealed top and bottom. Vacuum applied.

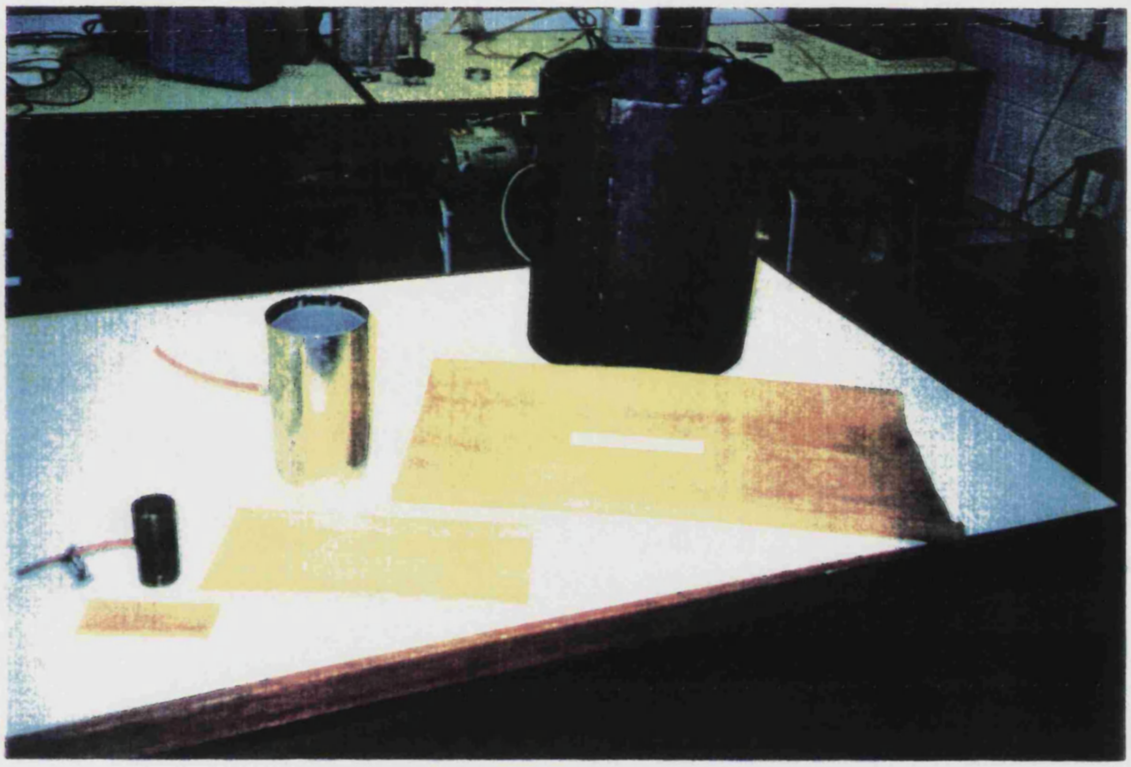


Plate 6.12 Comparison between formers and membranes for the 38mm, 100mm, and 254mm diameter samples.

7.0 INSTRUMENTATION

The way in which data is recorded and presented often affects our comprehension of the mechanisms that the data represents and also our reponse to such data. It is important to be aware of any influence the recording methods and apparatus may have on the data being monitored. Early work on the dynamic behaviour of soil samples that relied on the real time plotting of the hysteresis loops from dynamic tests, led to the 'real' data being modified as a result of the damping inherent in the mechanism of the plotter. This additional damping resulted in the hysteresis loops having rounded ends which in turn affected the calculation of the damping component, and also complicated the determination of the shear modulus. The wiring and interconnecting elements of a monitoring system need careful attention in order to not modify the 'signal' and to thus record the true sample response.

Within this study various forms of sensors were used to monitor the response of samples. The static tests on the 38mm and 100mm samples utilised various direct read instumentation such as proving rings, dial gauges and analogue gauges. As long as these instuments were read perpendicular to their faces, and correct conversion charts used, and suitable calibration certificates available, they presented few problems. The remote monitoring of electrical sensors required appropriate consideration.

The remote data logging system was based around a programable data aquisition unit (ADU) that could be configured to monitor up to 64 channels, dependent on the modules fitted. A PC compatible computer was connected to the ADU via an RS232 interface to provide control; this also allowed real time screen plotting on the PC of the monitored channels against time. As the frequency of the loading cycles was low the data transfer rate of the serial interface was not a problem. Data was also logged by the ADU, then down loaded to the PC after each test, at which time the data could be processed and X,Y plots produced. The sensors used in this program varied from proprietary systems, to instruments manufactured by the author specifically for this program of study. The sensors used and components of the monitoring system will be explained in the following sections. The complete system is shown diagramatically in figure 7.1.

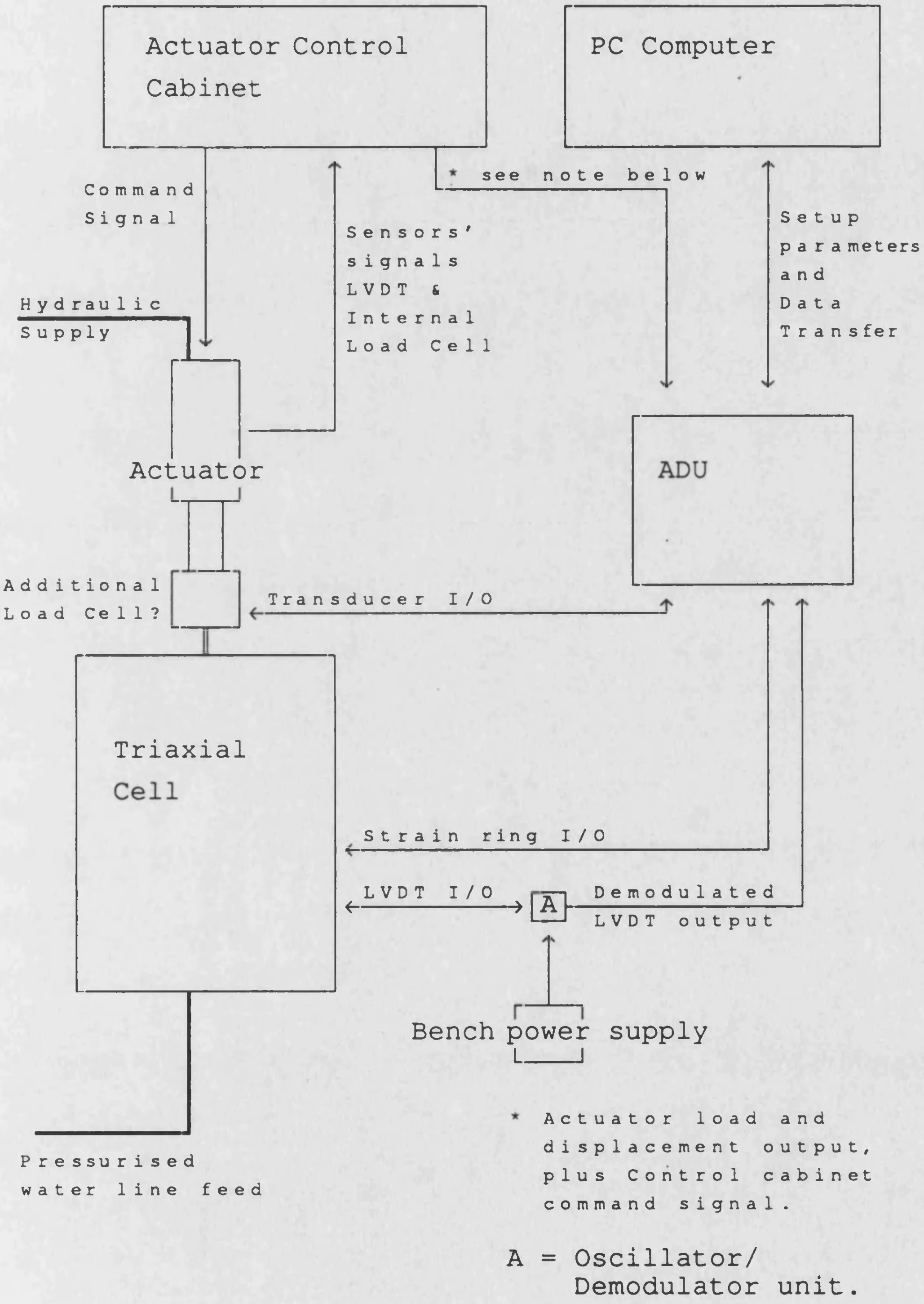


Figure 7.1. Monitoring and control system (Diagramatic)

7.1 STRAIN GAUGE DISPLACEMENT TRANSDUCERS

These are proprietary displacement transducers that utilise the strain gauge Wheatstone bridge arrangement to give an electrical signal proportional to linear displacement. The use of strain gauges is commonplace within the industry, and there is no need to go into detail as to their workings. The transducers available for this project utilise the cantilever principle, whereby a wedge connected to the spindle forces apart two cantilever beams housed within the body of the transducer. Transducers of this type tend to have a long body length relative to the range of movement. Each cantilever beam has two strain gauges wired in the half bridge arrangement. The resulting wiring out of the transducer is a four wire connection giving supply +ve/-ve and signal +ve/-ve. The instruments each have a calibration certificate detailing the response characteristics and sensitivity, and these are included within appendix 4. The transducers require a DC supply voltage which was supplied from the ADU in the form of +5V to -5V, giving 10V. The resulting output of the gauges used was between 37mV and 54mV.

7.2 LINEAR VARIABLE DISPLACEMENT TRANSFORMERS (LVDT)

These are proprietary instruments that work on the principle of the variation in current induced by the movement of a conductor within an alternating electrical field. The system involves a primary coil connected to the supply current, and two secondary coils connected such that with the spindle in the middle of its travel there is no phase difference between the excitation and output signal. Any movement of the spindle from this null position results in a phase shift between the supply and output current which can be analysed and converted into a variable voltage signal proportional to the displacement of the spindle. The primary coil requires an AC power source in order for the instrument to function. This is normally provided via an oscillator demodulator unit connected in line with the transducer, which also deals with the initial signal conditioning, converting the phase difference into a variable signal that can be monitored with a normal data logger. These transducers are normally much shorter relative to their range of movement because the operating mechanism is much more compact. LVDT's allow very high resolution which is useful when measuring low strain levels. The devices used in this study were placed within the cell and thus the main body and connecting wires had to be waterproofed. The oscillator demodulator unit required a supply voltage between 12 - 24V DC, which was outside the range of the ADU necessitating the use of a separate bench power supply. The output signal from the oscillator demodulator unit varied between ±6V and was logged by the ADU.

7.3 STRAIN RINGS

These were used to assess the radial expansion of the samples. The principle, design and manufacture has been detailed elsewhere, we deal here with the handling of a signal from these devices. The strain rings as already described each made use of two pairs of strain gauges wired in 1/2 bridge arrangements. Due to the versatile nature of the ADU, these could be directly wired into the appropriate board. The ADU powered the bridge circuit with a constant current source, and monitored the output signal. It must be noted that extreme care must be taken when wiring up bridge arrangements to ensure that only the variable resistance of the strain gauges themselves is recorded. In particular, the wiring connections to ensure the common potential of the measuring circuit must be made at the gauges, and not at the connector. This is illustrated in figure 7.2. Figure 7.2(a) illustrates the correct wiring connections showing the sense, input, and output connections being made at the gauges themselves. A common misconception is that since the pairs of wires ab,cd, and ef are connected at common points, that the same electrical configuration is achieved by the simpler arrangement illustrated if figure 7.2(b). In this case the wires are paired at the connector. Whilst this simplifies the wiring, it adds extra resistance by including part of the wiring circuitry within the 'bridge' circuit. This reduces the sensitivity, and increases the possibility of changes in reading without a change in the resistance of the gauges themselves.

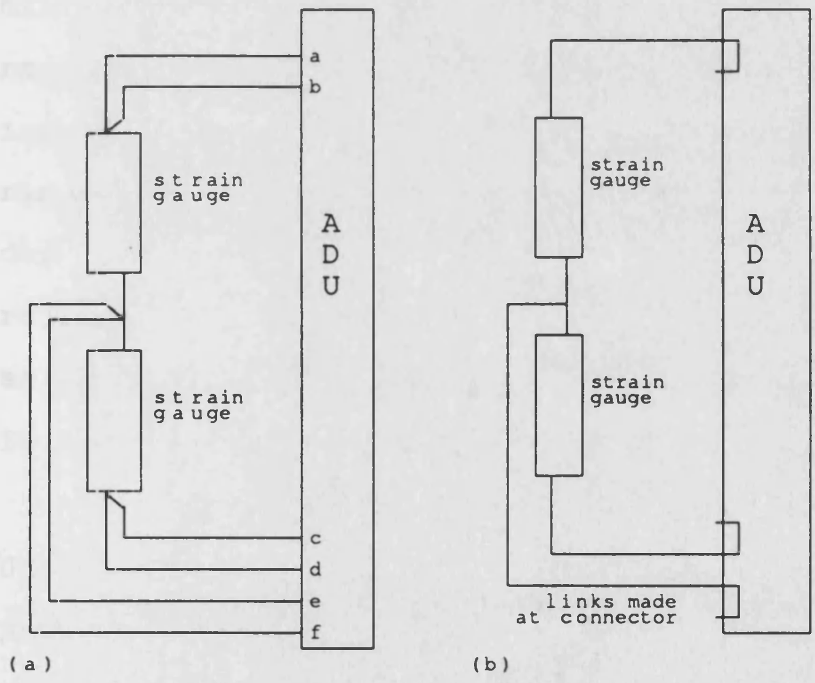


Figure 7.2. Common potential wiring details for 1/2 bridge arrangement. Showing (a) correct, and (b) incorrect method.

Each of the strain rings had to be individually calibrated to give factors to convert the output readings from the 1/2 bridges to expansion/contraction of the diametrically placed fixing points. These tests and charts are detailed in section 8.1.

The supply source and wiring details for the 1/2 bridge arrangement is given in section 7.4.

7.4 DATA AQUISITION UNIT (ADU)

The ADU is a programmable data logger utilising a 12 bit A/D converter, which allowed for a maximum possible resolution of 4095 units over the +ve/-ve full scale input range. This was split between 2048 for the +ve range, and 2047 for the -ve range; the difference is due to the use of 2's complement notation by the ADU to represent negative numbers. The system allowed selectable gains over a range between ±10v to ±9.8mV in 11 ranges as shown in 7.1.

Using the calibration certificates provided for the proprietary transducers and determining the appropriate gain ranges allowed the resolution of the measurement signals to be maximised. Entering conversion factors into the controlling software meant that the various sensors could be monitored in real engineering units.

Gain No.	Signal Range	Resl^n.	Gain
0	±10V	4.88mV	*1
1	±5V	2.44mV	*2
2	±2.5V	1.22mV	*4
3	±1.25V	0.61mV	*8
4	±625mV	305μV	*16
5	±312mV	153μV	*32
6	±156mV	76μV	*64
7	±78mV	38μV	*128
8	±39mV	19μV	*256
9	±19mV	9.5μV	*512
10	±9.8mV	4.8μV	*1024

Table 7.1. Gain Ranges and Resolution of ADU.

The PC controlling computer utilised software provided by the suppliers to configure the ADU and process data; direct commands were also sent to the ADU on a number of occasions to simplify the logging procedure. A number of software packages have been developed by the author during this programme that provide more direct control of the ADU functions. Use of the RS232 interface with direct ASCII 'string' commands enabled a small hand held computer/processor to control the data logging operations. This increased the portability of the system and proved ideal for the early preliminary work. For the screen display of a number of channels and graphical output of data the PC was the more appropriate mechanism and provided the facility of screen dumps to printer.

The excitation voltage for the 1/2 bridge strain gauges utilised a 8.33mA dual current source, which resulted in the six wire connection shown in figure 7.3.

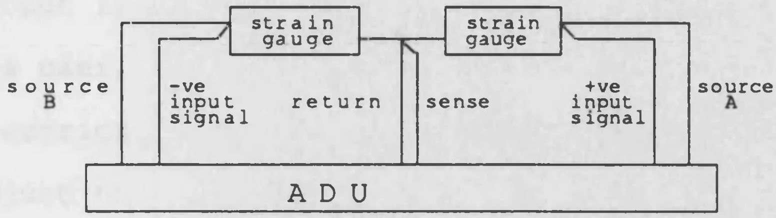


Figure 7.3. Six wire connection for 1/2 bridge.

7.5 DIGITAL CONTROL SYSTEM FOR HYDRAULIC ACTUATORS

This is a state of the art modular digital control feedback, monitoring, and plotting system, manufactured by DARTEC under their 9500 series, incorporating analogue monitoring devices and digital processors.

The hydraulic actuators connected to this control system all incorporate load cells and LVDT's which provide signals that can be monitored by the system controller. These signals indicate the exact position of the actuator ram; the digital contol system operates by incorporating these signals into a feedback loop. This allows the operation of the actuators in either stroke or load control. Although, in essence, all tests could be considered to be 'positionally' controlled, since, it is hydraulic fluid under pressure acting against the ram that induces the load. This hydraulic fluid passes through a Moog valve which allows remote control by electrical signal, thus varying the rate of flow, and porting of fluid pressure to the ram. By comparing the output from the sensors with expected values entered by the user, or calculated from setup information, the electrical input to the Moog valve can be varied to adjust the direction of movement of the ram and thus the load applied to the sample to follow a predetermined ramp. It is the fast and accurate control of this electrical system, and matching to the hydraulic response of the mechanical hardware that allows the successful operation of this system. The hardware provides the response of the actuator sensors as a ±10v signal, and these were also recorded by the ADU.

The actuator response is a function of the electrical feedback loop and the mechanical hydraulic system providing the hydraulic pressure, which in turn is dependent on the capacity of the valves incorporated on the actuators. The response of the feedback loop was dependent on the electrical gains incorporated within the system, which could be varied to suit the stiffness of the sample under test. It is important to match the feedback parameters of the control system to the expected stiffness of the sample if testing 'flexible' specimens. The only variable on the pressure supply system was the pump supply pressure, and this was held constant at the actuator setting of 207 bar (3000 psi).

7.6 LOAD CELLS

All the load cells used in this study employed the full strain gauge bridge principle, in basically the same manner as a strain gauge displacement transducer. In fact, as far as the ADU is concerned the two instruments are identical. Two types of load cell were used: indicating load blocks, and those requiring an external data logger. The indicating type contain their own power source (9V battery, or mains adapter) and signal conditioning, giving a direct readout of load on a digital display. The resolution is predetermined by the inbuilt electronics and limitations of the display. Those requiring an external data logger utilised the ADU to provide a 10V supply and to monitor the output signal. The resolution of the recorded data could be varied, within the tolerance of the bridge arrangement itself, by selecting different gain settings on the ADU. The output is scaled by user defined variables.

PART III

Testing Program

Includes all information pertinent to the tests so far completed and their interpretation, the results, conclusions and suggestions for further work.

8.0 LABORATORY TESTING PROGRAM

This section deals with the testing program carried out to date, and covers theoretical aspects associated with selection of test method and data interpretation. The development of the strain rings was an integral part of the apparatus for the dynamic testing, and so their calibration is covered in some detail.

The developmental nature of this thesis work has meant that certain areas of 'laboratory' work have already been covered. The full laboratory program consisted of various stages, a brief listing of which follows.

(1) Modification of original static loading equipment to allow dynamic testing. This involved developing a computer controlled stepper motor system to adapt the constant air/water system for cyclic loading. This was outlined in section 5.2 with additional information in appendix 2. In the event this work was not carried forward.

(2) Commissioning of large cell and pressure testing. Following manufacture of the new triaxial cell, the apparatus was assembled and pressure tested to ensure testing could be performed safely. As detailed in section 5.1 the cell was pressurised to 4137 kN/m^2 (600

psi). The pressure release valve was set at 1379 kN/m^2 (200 psi) providing a substantial factor of safety.

(3) Fabrication of strain rings. This was described in sections 6.2.2.1 and 7.3, covering the methods and materials required..

(4) Calibration of strain rings. The nature of the strain rings meant that they had to be carefully calibrated in order to provide useful data. Full operational characteristics of the rings is detailed in section 8.1.

(5) Initial static comparison tests between 38mm, 100mm, and 254mm diameter samples on similar material. The primary aim of these tests was to establish if there was any scaling effect between the different cell sizes.

(6) Extended program of comparable static testing. As outlined in the introduction, the developmental phase comparing the results from the different cells on similar material, suggested that the different cells yielded different results. This required further investigation to verify comparisons between the cells. Whilst smaller grained material could be tested in each of the triaxial cells, only the 254mm cell could be used

for the larger grained material, and thus cell size effects would need to be assessed if valid comparisons were to be made.

(7) Static tests on large grained particulate material (Limestone grit) in 254mm cell. Single sized material tests to enable comparisons between graded and different single sized samples.

(8) Cyclic loading tests. The additional static tests detailed above, and operational difficulties curtailed much of this testing program. Preliminary testing is described and operational charactaristics detailed.

A preliminary requirement to the initiation of the testing program was the commissioning of the new structures laboratory facilities. These included a hydraulic ring main feeding four outlet stations to which hydraulic actuators could be connected. Hydraulic pressure was provided by two pumps interlinked by a common oil reservoir. The pumps fed independently into the ring main, with an isolation valve allowing independent and simultaneous use of the two pumps to feed different actuators. Alternatively, if the pressures of the pumps were matched they could both feed into the open system giving an increased flow rate, resulting in a faster response of the actuators. A wiring loom linked the four outlet stations, both pumps, and pump control panels allowing the interlinking of the digital control cabinets between the various framed and loose actuators, as required. The control cabinets could be interchanged between stations, which was essential for the dynamic testing.

The large triaxial test facility, which consisted of the triaxial cell, steel 'H' frame with stabilising arms, and either 50kN or 100kN hydraulic jacks, and associated data logging and control equipment, was placed on an area of the strong floor as shown in plate 8.1. The horizontal cross member of the 'H' frame was movable which allowed the interchange between the 50kN fatigue actuator, and the 100kN static jack arrangements.

8.1 STRAIN RING CALIBRATION

Following the procedure outlined in section 6.2.2.1 each of the strain rings required calibration to determine their suitability for the test programme.

Each ring was placed within a hydraulic testing frame as shown in plate 8.1, and subjected to a cyclic ramp under displacement control, at a frequency of 0.1 Hz. Maximum stroke amplitude was ±2.5mm. The response of the strain rings, ram displacement and load applied as determined from the control LVDT and load cell, were all monitored and logged using the ADU. This allowed the various responses of the rings to be displayed on a linked PC screen as real time plots against time. Sample readings were also logged and the resultant displacement against strain ring response graphs were plotted, for each 1/2 bridge. Examples of these plots are shown in figures 8.4 and 8.5. Full print outs of the logged data and graphical plots are included in Appendix 4.

From this graphical output, calibration values could be established to convert the signals from the strain rings to displacement, giving the lateral expansion/ contraction of the rings, and hence the soil sample when the rings are connected. Both the response against time and response against displacement graphs were used for these calculations. On both types of plot the vertical axis (labled NON) is the response of each 1/2 bridge in ADU units (as described in section 7.4). Selection of the highest gain possible for each bridge gives the best resolution. The gradient of a line drawn through the end points of the hysteresis loop plots gives a direct conversion factor in appropriate units. This of course, is only valid for the purpose if the hysteresis loop is very narrow and follows a regular 'closed' path on repeated cycles. This value is representative of the loop as a whole, on both the extension and contraction

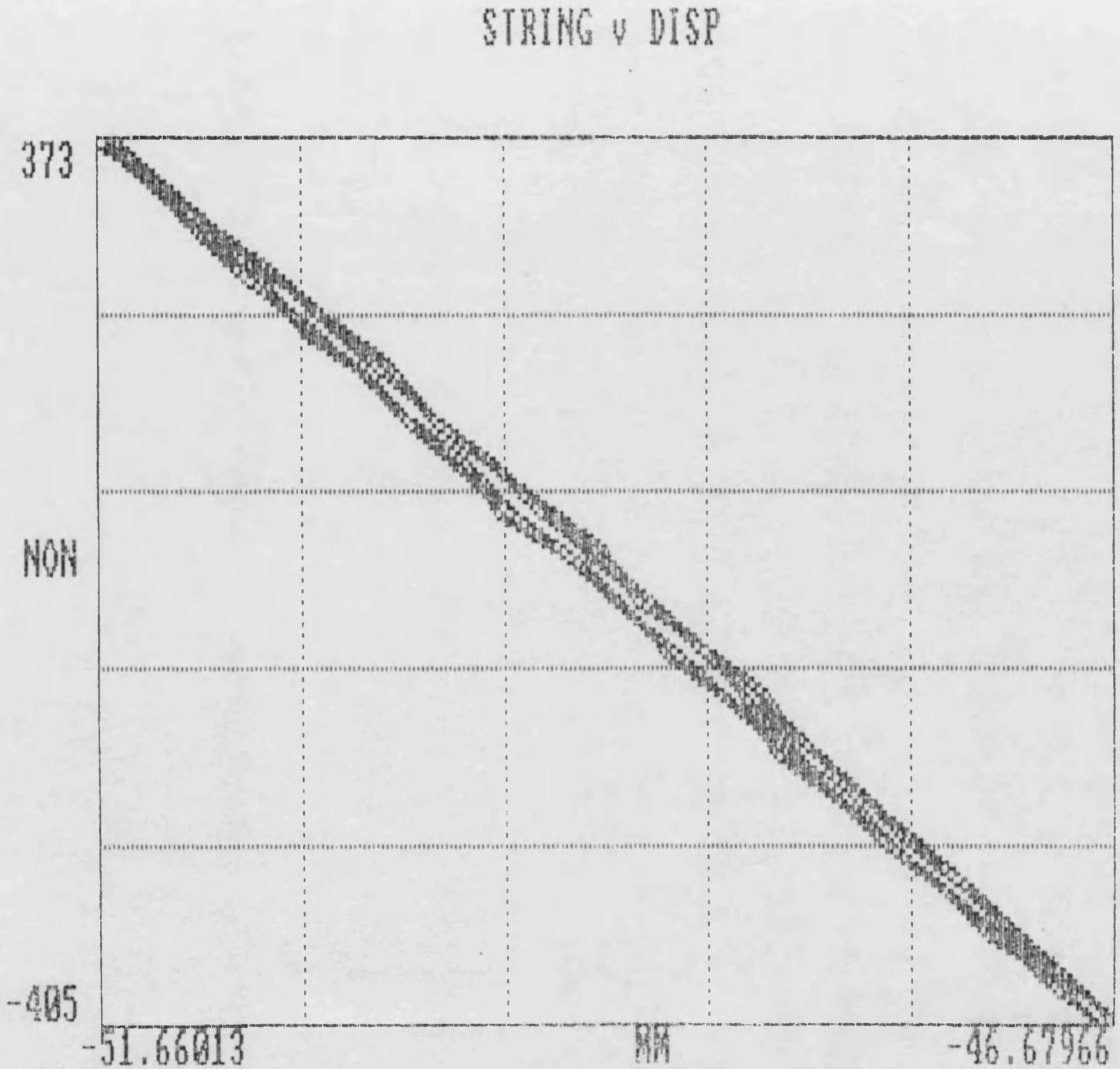


Figure 8.4. Sample plot for strain ring 1/11
Response vs Displacement plot.

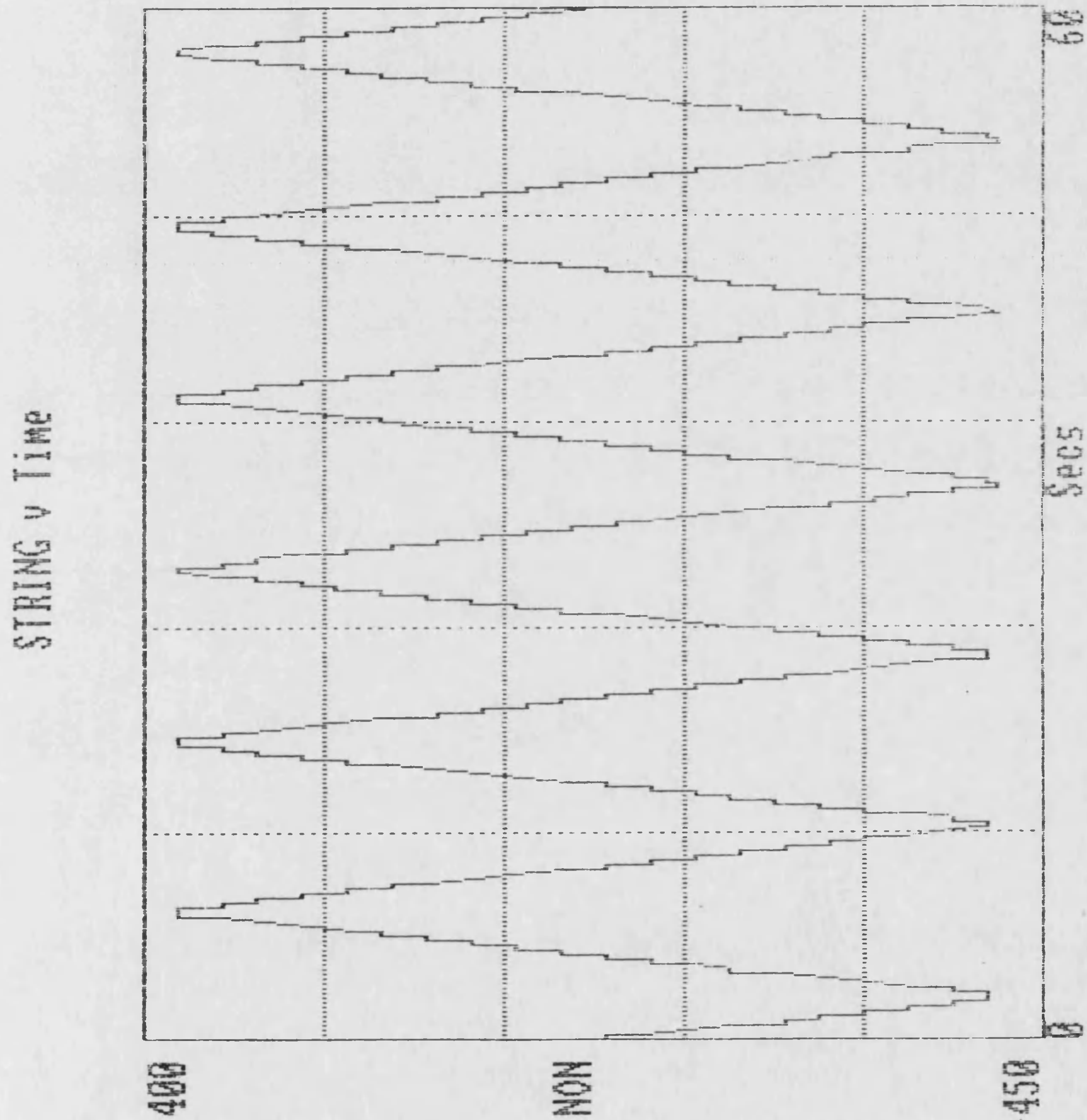


Figure 8.5. Example plot for strain ring 1/11
Response vs time plot

phase. The wider the loop the less accurate this figure. Given that the tests were run under stroke control the amplitude of the response measured peak to peak on the time plots, must match the stroke limits of the ramp. As given previously, this was ±2.5mm. Comparison with the ADU unit scale again gives a conversion factor in the appropriate form. Care must be taken with this procedure, as the recorded points may miss the extreme points of the ramp.

When recording data versus time, the rate of data aquisition must be matched to the response of the specimen and rate of load/displacement application. In dynamic situations this is especially important. If the recording rate is too slow the true nature of the response is averaged over a wide time frame, and in extreme cases can mask any movement at all. Ideally the rate of data aquisition should be at least an order of magnitude greater than the induced motion. A further problem arises if the recording is out of sequence with the response. In this case the peaks may be missed. When this occurs the measured response gives a distorted pattern which itself is cyclic in nature.

The calibration values for each ring are tabulated in table 8.1. Each strain ring required two channels, one for each 1/2 bridge, and the conversion factors are identified with respect to the ring number and channel used to monitor the respective bridge.

Ring No.	Bridge Channel	Conversion mm/ADU unit	Gain
1	11	6.403×10^{-3}	10
	15	7.525×10^{-3}	10
2	13	14.23×10^{-3}	9
	14	15.09×10^{-3}	9
3	12	8.125×10^{-3}	10
	16	8.91×10^{-3}	10
4	9	16.12×10^{-3}	9
	10	31.13×10^{-3}	8
5	12	8.893×10^{-3}	10
	16	6.985×10^{-3}	10

Table 8.1. Conversion factors for strain rings

The stiffness of the rings was so low that the load cell could not register any change in resistance as the rings flexed. This indicated that the rings would have negligable influence on the expansion/contraction of the soil samples when placed in position.

In order to quantify the stiffness of the rings a series of simple static loading tests involving hanging small weights from each ring and recording the resultant deflection was carried out. The deflection range was limited to that used for the cyclic calibration tests. These tests yielded an average stiffness value for the rings of 2.0 mm/N. Full results are included in appendix 4.

Moving back to the output produced from the calibration tests, the plots of displacement against output from the gauges with their hysteretic form, indicates that there is some damping within the system. Whilst it is not possible to quantify directly from these plots due to the absence of a load response from the cyclic testing, this will need to be considered when utilising the strain ring output to determine the damping of soil samples.

Both plots, output against time and output against displacement, indicate a high degree of uniformity for the response over a number of loading cycles. On the displacement plots the hysteresis loop does shift very slightly with increasing load cycles. This is most noticable during the early stages, and reduces after a number of cycles have occurred. It was noted that the fixing of the rings was of prime importance in achieving consistant results. The fixings used to locate the rings in the testing frame for the calibration exercise were the location studs previously described, and as used for locating the rings into the soil samples in the triaxial cell.

The 'absolute' output from the strain rings does tend to drift with time. The type of araldite was selected to reduce the temperature effects to a minimum. Whilst the drift in 'absolute' output does not generally affect the conversion factor, re-calibration should be undertaken prior to each testing period.

8.2 MATERIAL SELECTION

As previously mentioned, this project required the formation of samples of graded granular material, utilising the additional size of the large cell. The results could then be compared to those from smaller more traditional cells in order to assess the effects of scaling upon the response of graded samples. A prerequisite to this work however, was the validation that all the different sized cells yielded similar results on similar grained single size material.

8.2.1 Material for Calibration Tests

Material for the 'calibration' exercise had to be uniform and allow suitable samples to be formed in sizes varying from 38mm to 254mm (1.5" to 10") diameter. The 38mm diameter samples thus limited the upper size range. Three gradings of sand were used for the initial batch of tests, and are detailed below.

(1) A fine sand, grade 52/100.

(2) A medium graded, Holm Sand.

(3) A course graded, Leighton Buzzard calibration sand, grade 14/25.

The grading curves are shown in figure 8.1.

These materials were already available in sufficent quantities within the department. A range of gradings was selected in order to establish if grain size had any bearing on the response as sample size varied.

Inspection of the 52/100 grade, revealed the individual particles to be very uniform (rounded) in shape and colour, suggesting some artificial processing, e.g a grinding mill. The Holm sand is dredged from the Bristol Channel, and is quartz based. As can be seen from figure 8.1 this material has a wider spread of particle sizes and will thus allow a more densely packed structure with fewer voids. The Leighton Buzzard sand, usually used in the replacement method determination of bulk density, was more single sized than the Holm sand. It is a river washed material, with a more irregular particle shape than the finer sand.

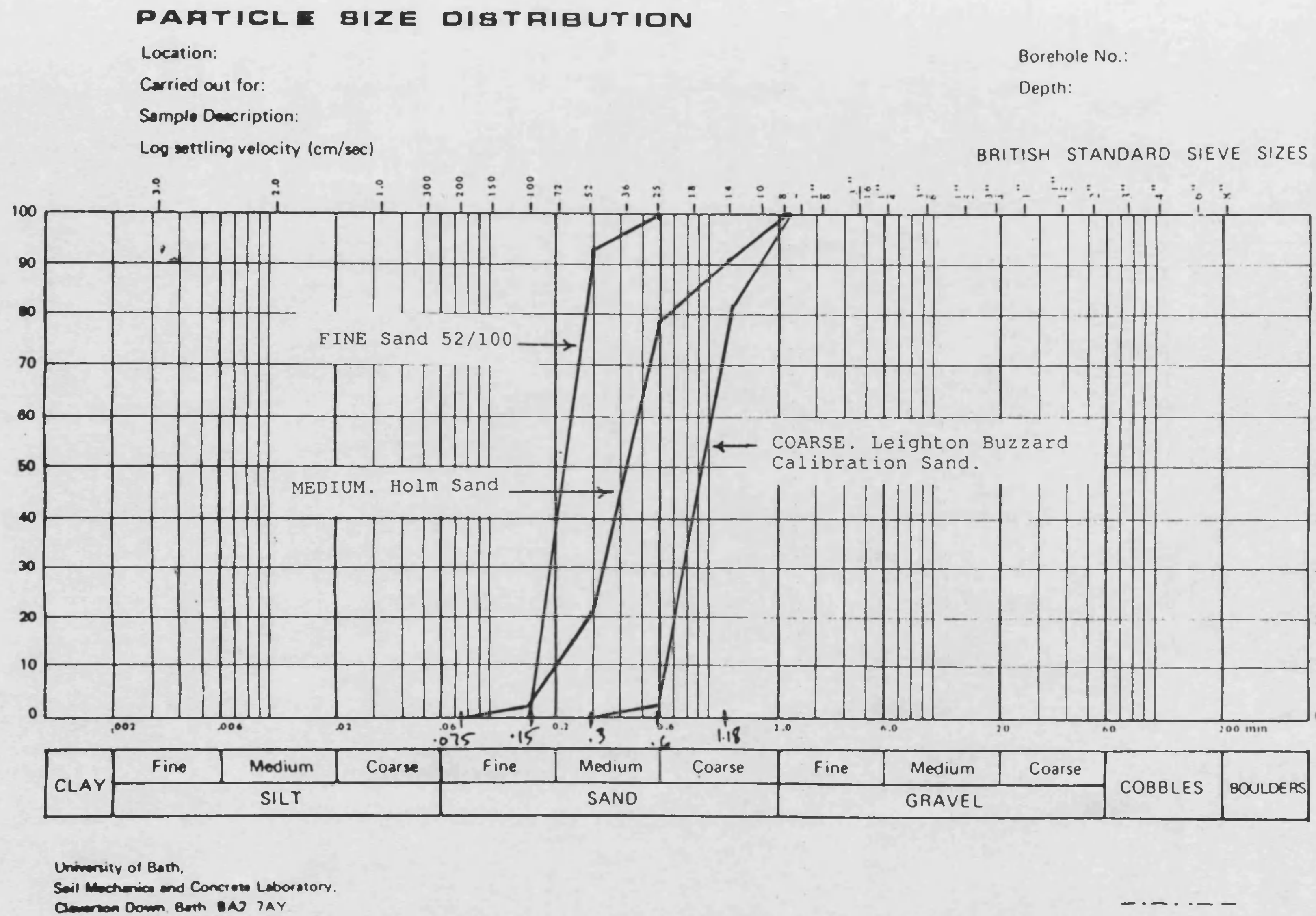


Figure 8.1. Grading curves for calibration tests

8.2.2 Material for Large Scale Tests

The requirement for these tests was to model a realistic material used in soil structures. The motivation for this investigation grew out of an interest in large earthfill and rockfill dams subjected to earthquake loading, thus the material to be modelled was selected from grading curves from actual built structures. Information was available concerning the construction of Mangla dam, built in Pakistan and completed in 1967. The grading curves for that project are shown in figure 8.2. This gave an indication of the range of sizes required to reproduce a graded sample that fell within the limits applicable to dam material. With the curve thus formed it may be shifted down the size axis to produce a well formed graded sample (i.e. no large voids, with the space between the largest particles filled with smaller grains, etc), suitable for testing within a 254mm diameter.

Continuing the initial link with embankment dams, the material for which is generally quarried/blasted local to the project, resulting in angular particles, a limestone grit was selected as a suitable material for testing. This was avaiable from a local source and donated for the purposes of this investigation. The material was delivered ready sieved in the following

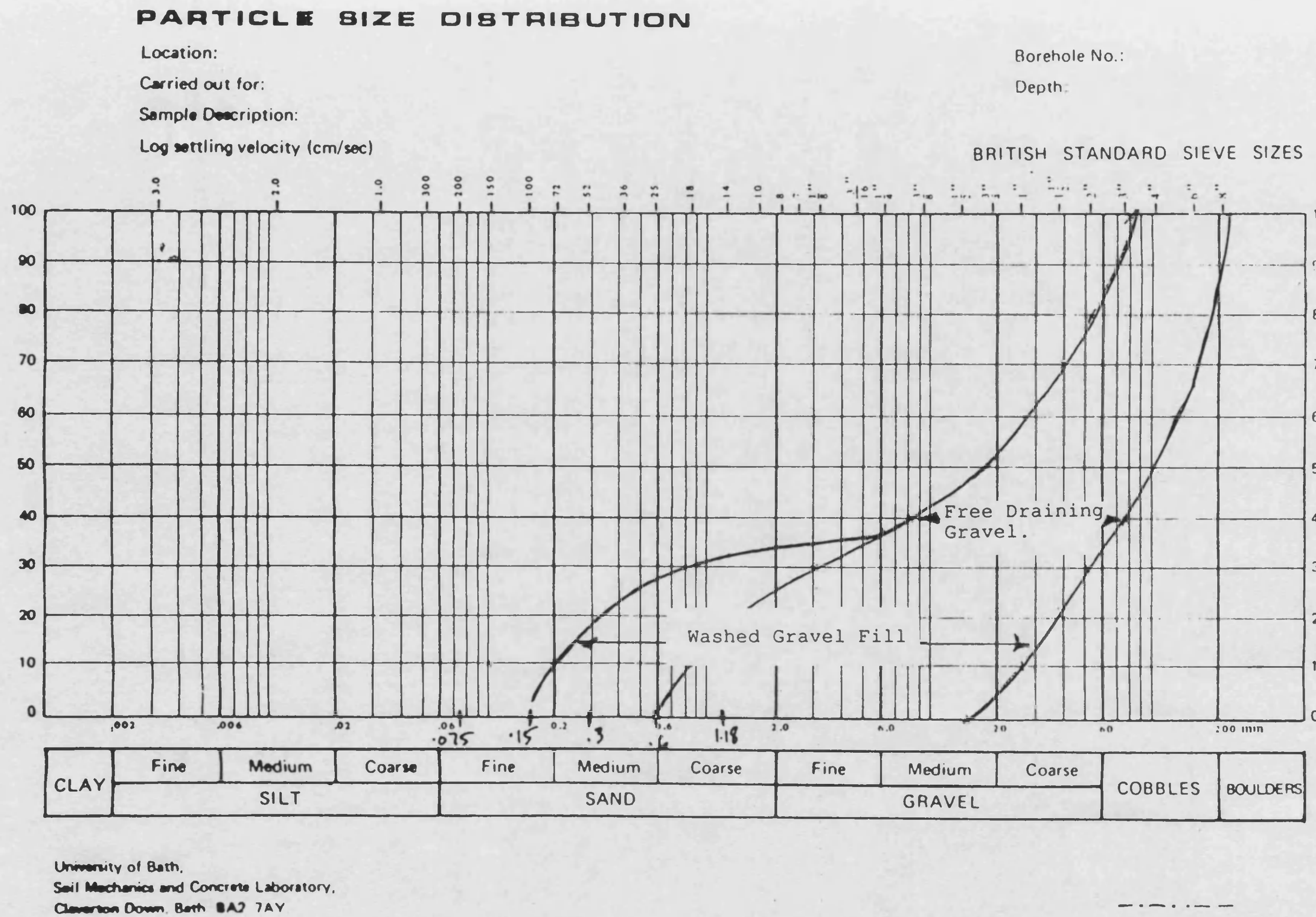


Figure 8.2. Grading curves for Mangla dam project

sizes, and was highly angular;

3mm to dust

10mm nominal

30mm to 20mm nominal

further sieving of the 3mm - dust element yielded the following sub divisions;

size 3mm to 2mm

size 2mm to 1mm

size 1mm to dust

This would enable a further reduction of the grading curve down the size axis to produce a graded sample for later testing in the 100mm cell, allowing investigation into the nature of producing 'scaled' graded samples.

In order to achieve a scaled down graded sample, the allowable limits of the full scale material were shifted down the size axis as shown in figure 8.3. The amount of shift was determined such that the upper size range lay within the practical particle size range that the large triaxial cell could accomodate. The size range that would be applicable is also affected by whether the sample is made from single sized or graded material. The more single sized the sample becomes, the smaller the

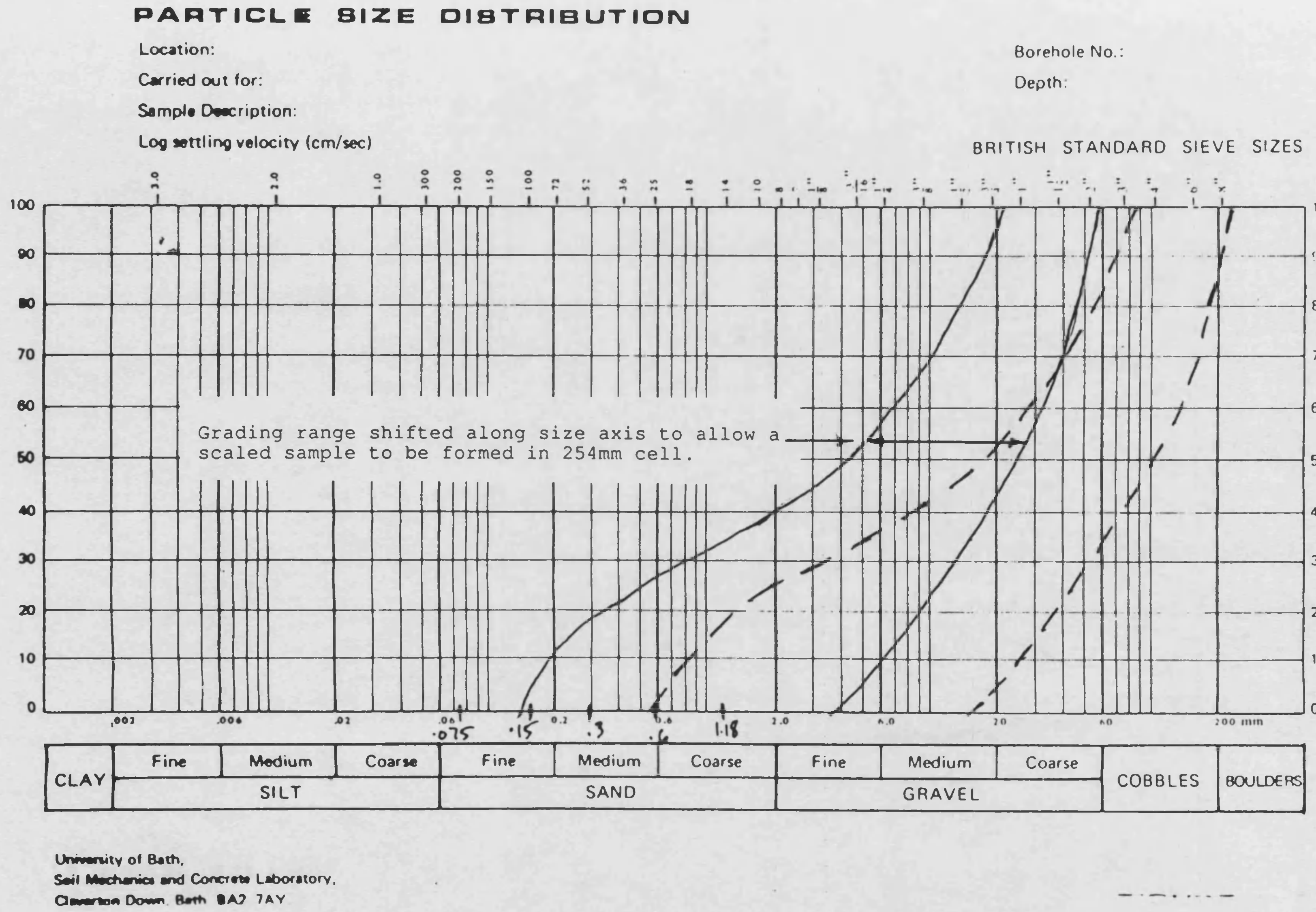


Figure 8.3. Grading curve shift.

individual particle size used to form the sample can be. This is in order to maintain a truly representative failure mode within the sample limits. In order to fully establish the effects of testing graded samples, each of the constituent sizes would have to be tested as single sized samples.

On the basis of the ratio of sample sizes between the 100mm and 38mm cells, it was felt that the large cell could handle material upto 60mm diameter. This is a conservative figure based on the extrapolation of data from table 13.4 given in "Manual of Soil Laboratory Testing", Vol 2, by K.H. Head. This gives suggested maximum size of particles for various nominal sample sizes, some of which are shown below.

Nominal sample size	Max. particle size	Particle/Dia. ratio
38 x 76	3.35	0.088
100 x 200	20	0.2
150 x 300	37.5	0.25
conservative suggestion for new 305mm diameter		
305 x 335	60	0.20
max. size used in this work		
254 x 335	30	0.12

The largest material available, as previously stated, was between 20mm and 30mm which was acceptable. This upper size range determined the shift of the grading curve and enabled a graded sample to be produced from the material available.

The graded sample was calculated on a percentage basis of material retained on selected sieves related to the limestone grit available in order to give a reasonably even distribution of the different sizes throughout the sample without cavities forming.

It was also the author's intention to consider the effect of angularity upon the response of large particulate material. A rounded gravel in suitable sizes proved difficult to locate initially, and time constraints eventually ruled this out.

8.3 CALIBRATION TESTING

These tests were conducted to establish the validity of comparative data produced from the different cell sizes. There is general appreciation that the sample size limits the size of particulate material that can be sensibly tested. Even with clays, the nature of the material, e.g. fissured or not, influences the choice of sample size, or at least the interpretation of the results. The sample has to be large enough relative to the constituent particle size to allow realistic deformation (particle rearrangement) to occur. One of the reasons for developing the large cell was to allow comparative tests on different scaled samples between different cell sizes, and so any effect of cell size had to be accounted for.

Care must be taken in the application of the quantitative results from these tests. They were of a comparative nature to compare values between cells, not primarily to determine absolute values. This is applicable to all the tests, and allowed greater freedom in the methods of sample preparation used, simplifying procedures and thus reducing time spent preparing samples. This is important, since it has been shown that various methods of preparation of granular samples influences the mode of deformation and thus affect the resulting values of friction angle.

8.3.1 Relevant Aspects of Test Selection

In order to provide a robust and simple - with careful interpretation - comparison between each of the cells, it was decided to establish the angle of friction (ϕ) for the material described in section 8.1.1, when tested at different sample diameters.

When dealing with granular material it is important to be aware of the differences between peak and ultimate shear strength, and thus peak and ultimate angles of friction respectively, hereafter refered to as ϕ_p and ϕ_u. These can be explained with reference to figure 8.6.

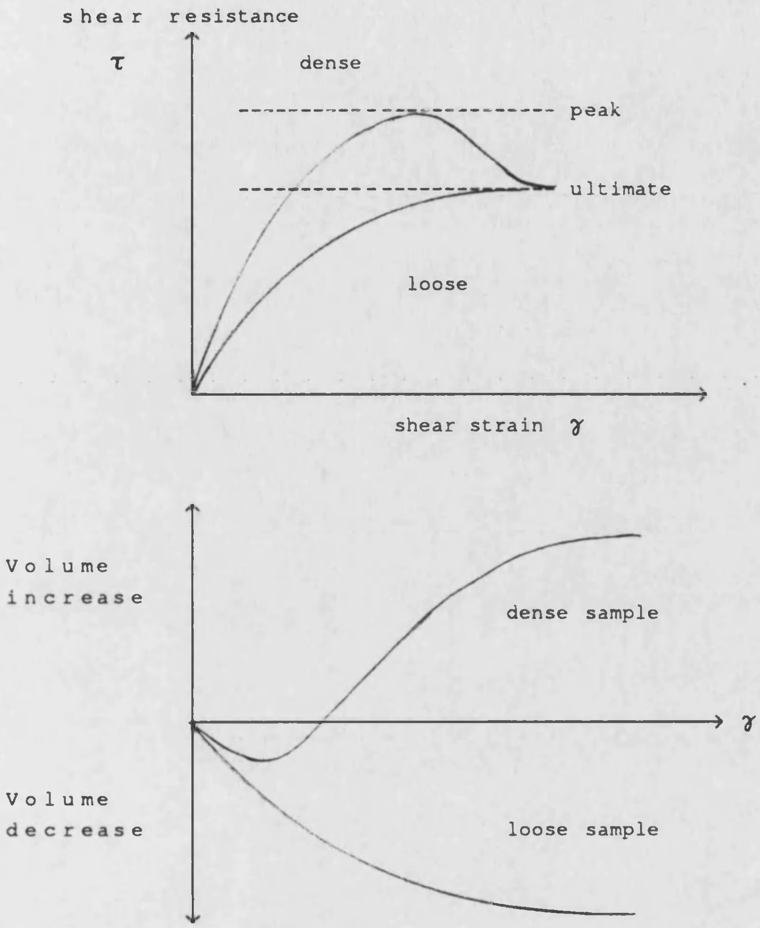


Figure 8.6. Explanation of Peak & Ultimate shear strength

For a granular material in its loosest possible state under the normal loads applied, the maximum shear resistance attained is the ultimate value. However, if the density of the material is increased and the test run at the same normal load a higher shear strength, the peak shear resistance is achieved at a lower strain level. If straining is continued then the strength drops, eventually to the ultimate value. These effects are related to the mode of deformation of, and particle rearrangement within, the different density materials. The ultimate value is related to a 'critical' void ratio under the specified normal load. Samples with lower densities than the critical state will contract when sheared, whilst those at higher densities will dilate giving rise to the peak values. The basic aspects of this mechanism are explained at length within standard reference books, and it is not considered necessary to explain the classic dilatancy model here. Of more interest is the effect of density on the angle of friction as shown in figure 8.7, after data from Bolton.

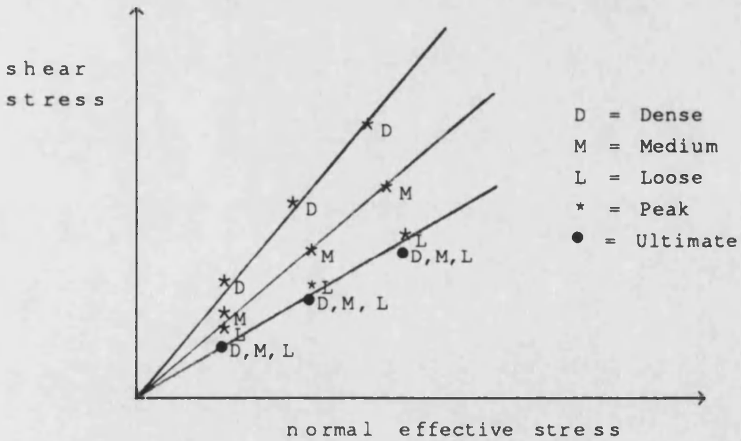


Figure 8.7. Change of ϕ with density. (After Bolton)

Bolton demonstrates that ϕ_u is unaffected by density, remaining constant. However, ϕ_p varies considerably with increasing density. Values suggested for clean dry sands are $\phi_u = 35^\circ$, and the range for $\phi_p = 35^\circ$ to 50°. Hettler and Vardoulakis (1984) presenting the results of tests on a medium sand in their large oversquare triaxial rig gave the relationship for the change in ϕ_p with density, shown in figure 8.8. Note, this density refers to the initial sample density at the start of the test.

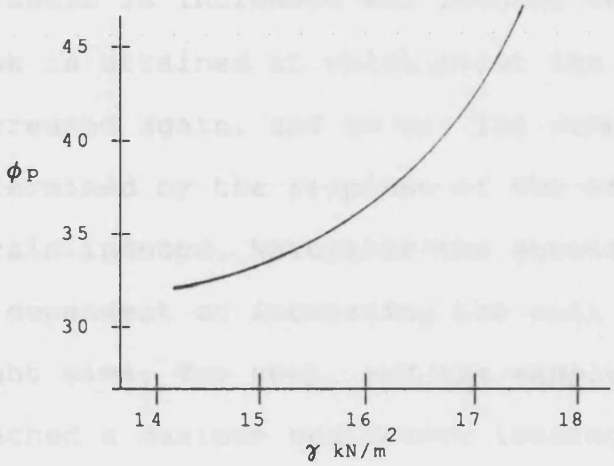


Figure 8.8. Density dependence on the friction angle (after Hettler and Vardoulakis 1984)

From this discussion it can be appreciated that interpretation of the angle of friction must consider the relative density of the sample.

8.3.2. Mode of Testing

To get representative values for the friction angles, it was necessary to test samples at a range of cell pressures and initial density. Due to the difficulties of forming samples of granular material, it was felt sensible to maximise the data from each test. Multi-stage tests were therefore utilised, yielding information for a range of cell pressures from each sample. The principle of multi-stage testing is as follows. The sample is set up at a cell pressure and the loading applied. The response of the sample is carefully monitored and as peak resistance is reached the cell pressure is increased and loading continued until a new peak is attained at which point the cell pressure may be increased again, and so on. The number of stages is determined by the response of the sample and amount of strain induced. Naturally the success of this procedure is dependent on increasing the cell pressure at the right time. Too soon, and the sample will not have reached a maximum resistance leading to a reduced angle of friction. Too late, and the sample may have 'failed' thus affecting the results for the following stages. Often the final stage offers the most accurate results since the loading can be continued through the peak, although the deformation must be kept within sensible strain limits otherwise end effects may influence the response. The resulting Mohr circle plots give a good indication of the consistency of the readings.

In order to successfully establish the appropriate point to increase the cell pressure, knowledge of the 'real time' stress resistance of the sample is required whilst the test is underway and the sample is deforming. It is when this response reaches a peak that the cell pressure can be increased.This was achieved by plotting the load, as measured on a proving ring or indicating load cell, on area correction paper. This is a standard technique used in strain controlled tests, whereby, assuming constant volume and uniform deformation, and knowing the rate of axial compression, the increase in cross-sectional area of the sample can be calculated for any point during the test. Utilising this information, an area correction graph can be constructed, whereby the vertical load axis reduces as the time axis increases. This takes account of the reduction in stress due to the increase in cross-sectional area as the sample compresses.

The validity of assuming constant volume needs to be clarified, as this procedure is more usually applicable to tests on saturated undrained tests. As previously mentioned all the tests were carried out on dry samples. Further, the sample preperation proceedure required an internal vacuum to be applied to the sample. This internal vacuum was released prior to the commencement of shearing, and the valve left open whilst shearing occurred, thus allowing the possibility of volume change. However, the volume change was monitored and found to have negligable effect on the results, and so the use of the area correction method as stated was justified.

A further point to bear in mind with multi-stage tests is the difficulty associated with changes of density at the different cell pressures. Granular material has a very low range of void ratio associated with changes from low to high relative densities, so a small change in volume can have a considerble influence on the density. But once again, it is the comparative nature of these test that is important, and the interpretation of the data will take these factors into account.

8.3.3 Method of Static Testing

The equipment used for these tests has been described at length in Part II. The overall test configurations will be described here.

The 38mm and 100mm cell configurations followed familiar lines, with the cells being placed within loading frames, controlling the rate of strain applied and the load being measured with proving rings of appropriate stiffness. Constant cell pressure was supplied from the air/water system previously described. The cell pressure was routed through a double manometer in order to measure the amount of water movement to the cell, allowing an assessment of the change of volume of the sample. An example of the 100mm cell configuration is illustrated in plate 8.2.

The large cell was placed on the strong floor beneath a load resisting frame. A 'loose' 50 kN actuator acting against the frame provided the loading, but again under stroke control. The actuator incorporated both load and stroke monitoring facilities via the integral load cell and LVDT. The control signal for these tests was the stroke channel, so the load response was displayed on the internal digital read out. As the load was being monitored external to the cell an assessment of the frictional characteristics of the ram/bush interface was required. This is detailed in section 8.3.3.1 below. The maximum load available of 50 kN limited the range of cell pressures to a maximum of 3 bar. This arrangement is shown in plate 8.1.

The rate of strain application for these tests was selected to permit adequate time to record the readings using the area correction procedure. The British Standard recommends static testing to be carried out at strain rates between 1% and 2% per min. A strain rate of 1% per min. was thus used.

The sample preparation procedure has previously been explained in section 6.4, only items of detail will be discussed here. The 38mm and 100mm cells both used modified formers normally used to form clay samples. This resulted in a slight reduction in the 'as built' sample height. This was brought about by the need to utilise some of the external former as a bearing lip for the base pedestal and top platten. The final diameter to height ratios were 1:1.76 and 1:1.67 for the 38mm and 100mm samples respectively. These ratios still fall within acceptable limits for use with standard end plattens. As previously explained the large cell utilised friction free end plattens allowing a sample ratio of 1:1.33.

A variety of preparation techniques have been developed and reported in the past. These vary from simple single pour techniques with constant pour heights, to methods involving preparation of the sample in two halves and inverting them prior to placement in order to overcome any gravity effects. The aim of the tests reported here required the consistent formation of samples at a range of densities in the three cell sizes. As long as the samples were formed in a consistent manner in each cell the comparative nature of the testing would be valid, which was the primary aim of the project. This allowed simpler preparation techniques to be used. The samples themselves were formed in layers, with each layer being tamped to achieve the required density. All tests in this series were run using dense samples, with relative densities in the range 70 - 80%.

8.3.3.1 Determination of Friction on ram/bush interface

The ram/bush interface utilised a PTFE bearing surface ensuring a running fit. In order to prevent water leakage under pressure, a U seal was also incorporated. In order to get an assessment of the friction induced as a consequence of this arrangement a series of simple dry tests (no water pressure applied to one side of the U seal) were performed. Only dry tests could be performed due to the lack of an appropriate water proof load cell. The test configuration is shown in figure 8.9

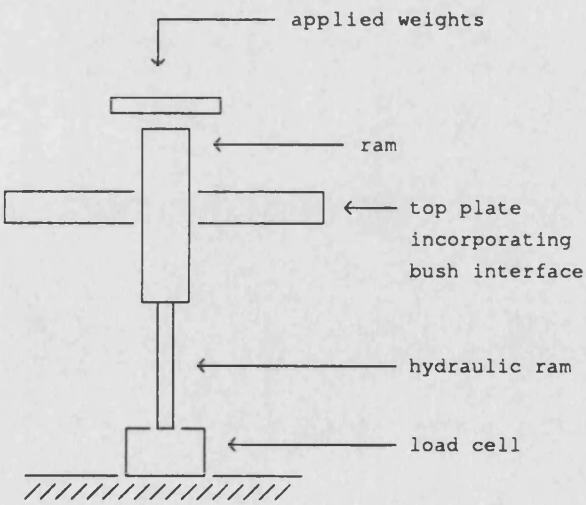


Figure 8.9. Layout for ram friction determination

Self weight of jack = 6 Kg
Self weight of ram = 10 Kg
$\Big\}$ total 16 Kg

Applied weights [Kgf]	Recorded load for upward movement [Kgf]
0	32
10	42
20	52
30	62

The consistent difference between the total applied loads and that recorded, of 0.157 KN (16 Kgf) indicates the friction when pushing against the seal.

Applied weights [Kgf]	Recorded load for downward movement [Kgf]
0	10
10	20
20	30
30	40

The consistent difference of 0.059 KN (6 Kgf) between total and recorded figures indicates the friction when pushing with the seal.

These figures are illustrative values. With an internal water pressure applied, the seal may increase the frictional forces. But for the static testing, values of this magnitude are negligible in comparison with the loads applied to the samples.

8.3.4 Summary of Results of 1st stage Calibration Tests

Three tests in each cell size were carried out for this preliminary stage. A sample plot of the multi stage readings is shown in figure 8.10a and the resulting Mohr circle plot in figure 8.10b. All test data is included in appendix 5, and summarised in table 8.2 and the Mohr circle plots illustrated in figures 8.11a,b,c.

	Friction Angle			
Sample size	Material Type Fine	Medium	Course	Cell pressure range
38mm	31-33*	33-35*	33	1 - 5 bar
100mm	36*- 38	38 - 41	38 - 39	1 - 5 bar
254mm	38	40 - 42	39 - 41	1 - 3 bar

Table 8.2 . Summary of preliminary Calibration tests.

* indicates that value associated with final pressure

Material Type: Fine = 52/100 grade, Medium = Holm sand
Coarse = 14/25 grade

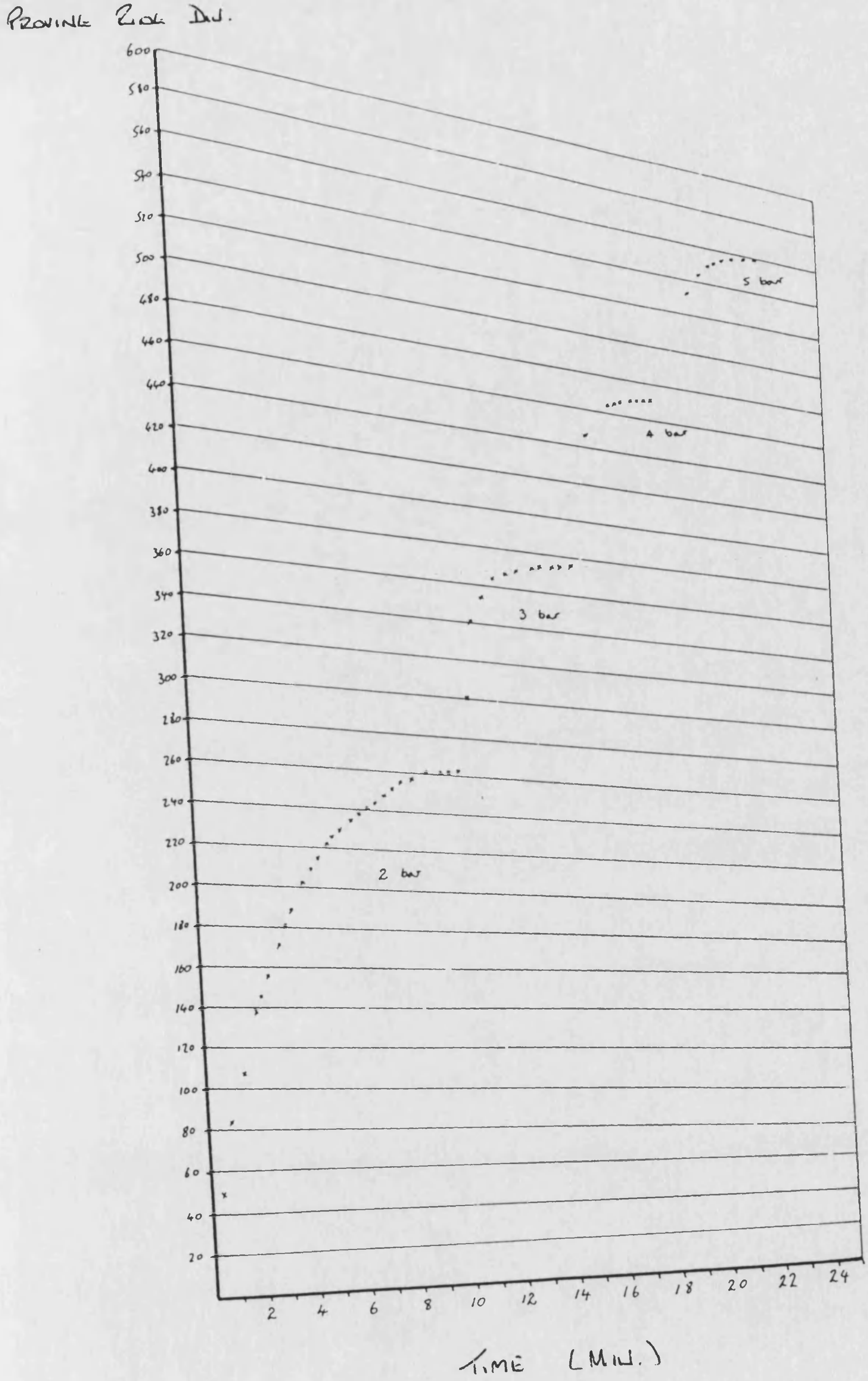
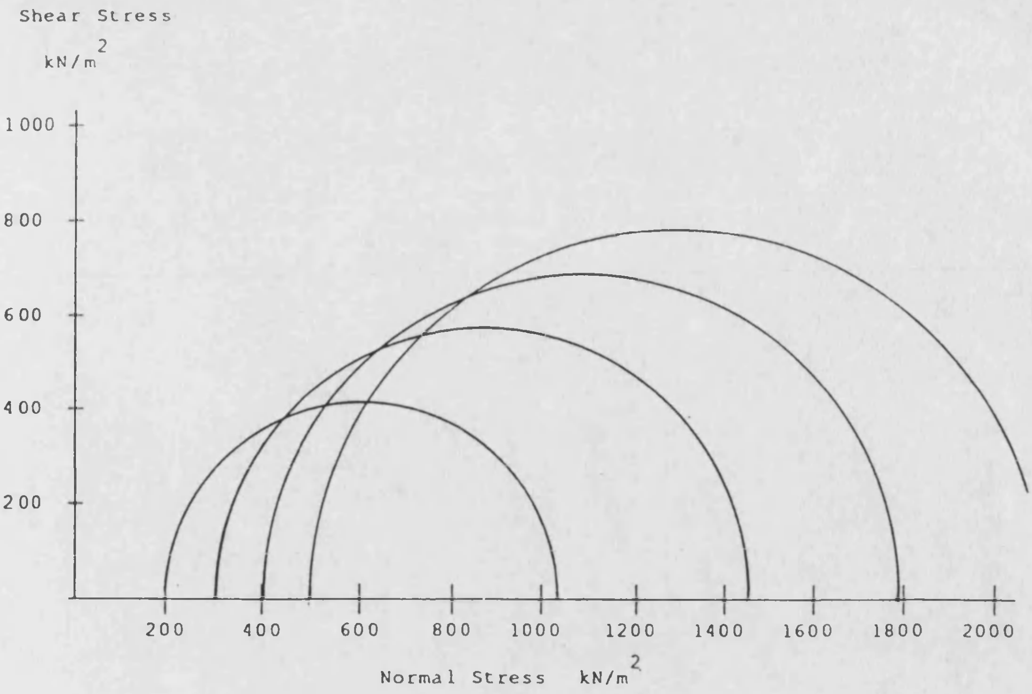
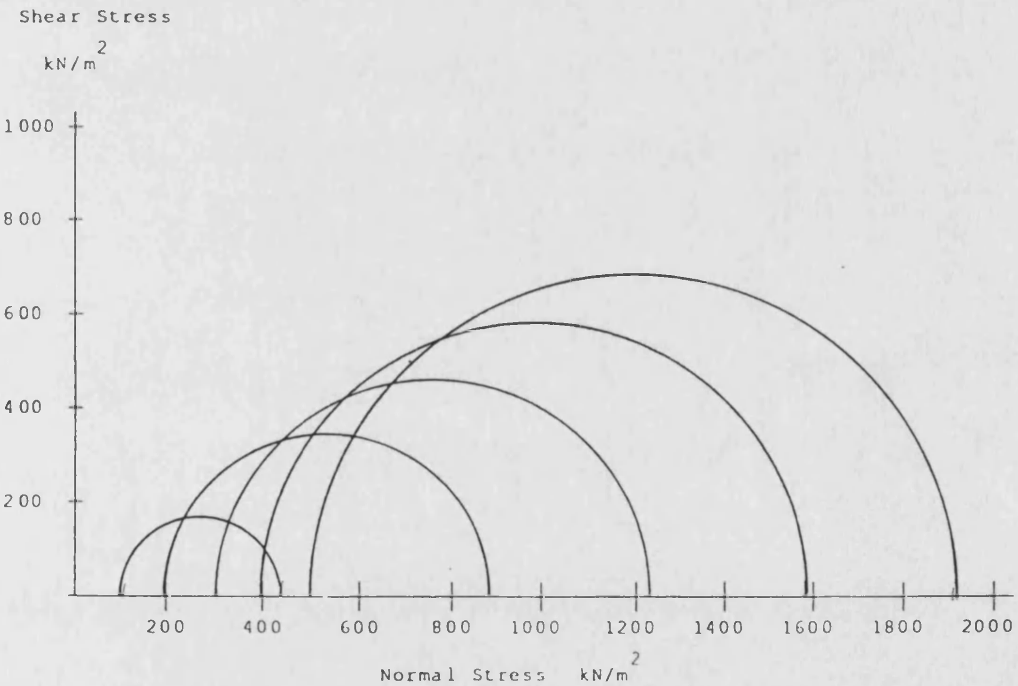


Figure 8.10a. Sample multi-stage plot on area correction paper.



Mohrs circle plot for Test No. 5



Mohrs circle plot for Test No. 6

Figure 8.10b. Mohr circle plot for multi-stage test shown in figure 8.10a.

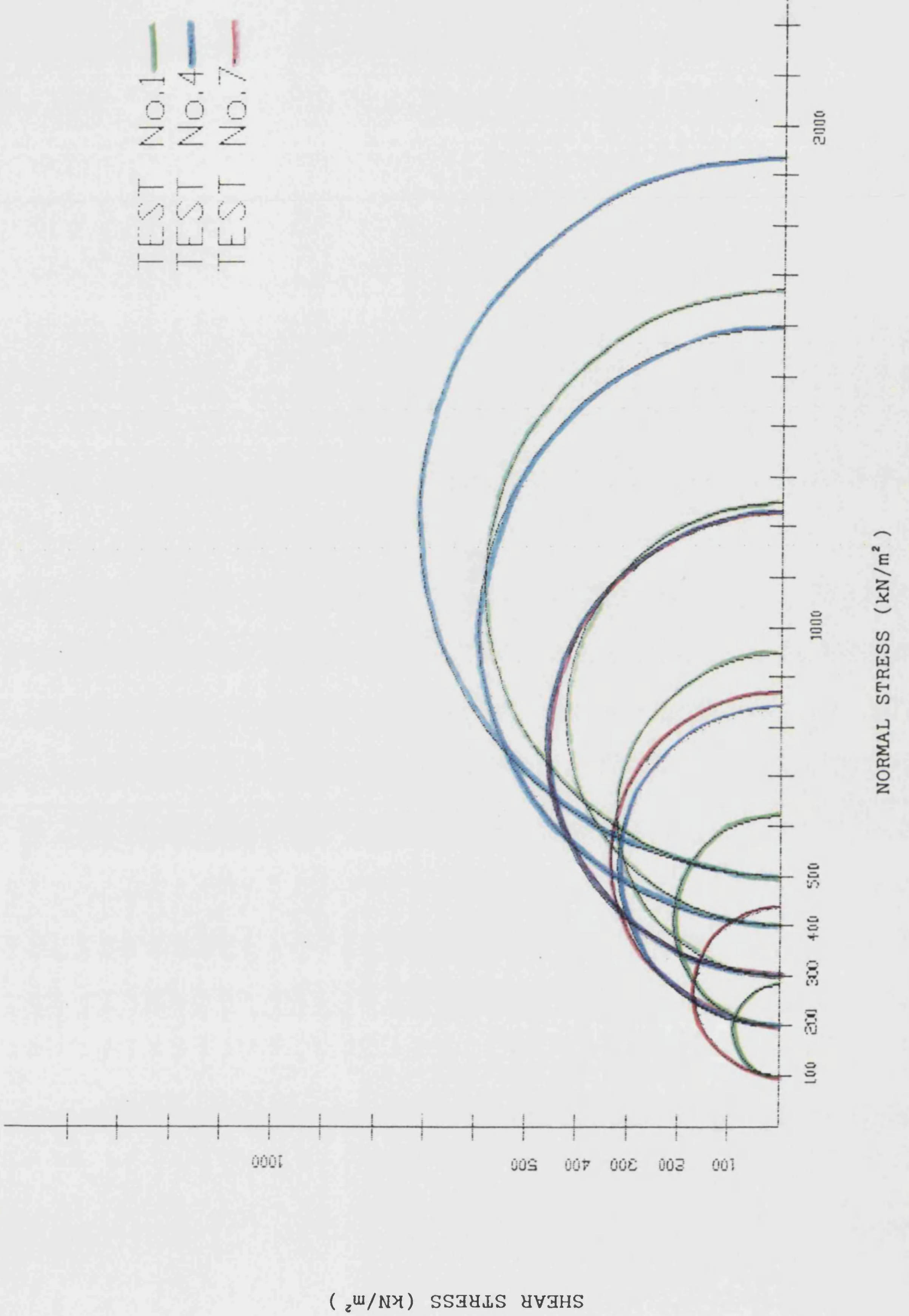


Figure 8.11a Combined Mohr circle plots for 'fine' grade samples.

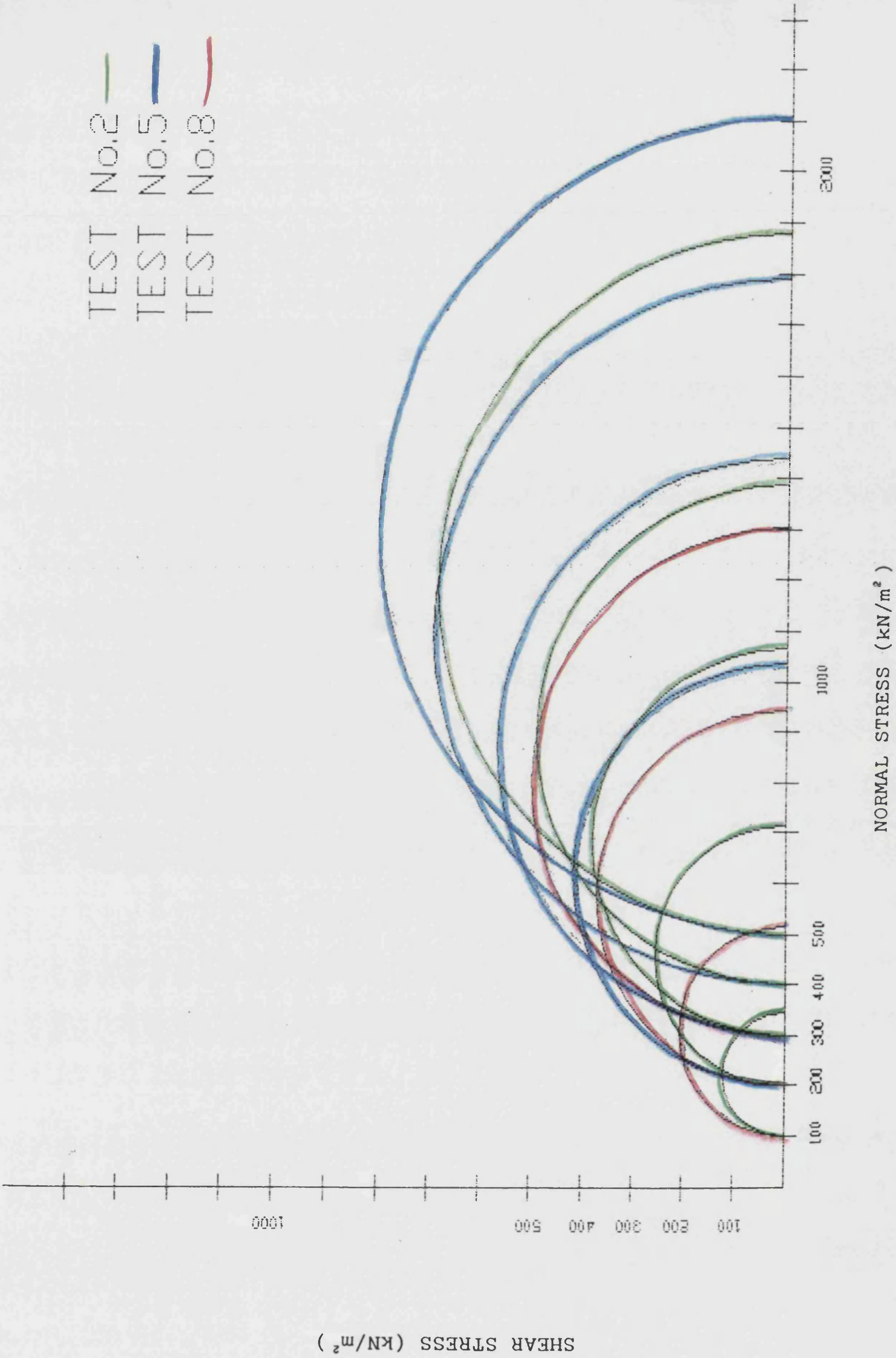


Figure 8.11b Combined Mohr circle plots for 'medium' grade samples.

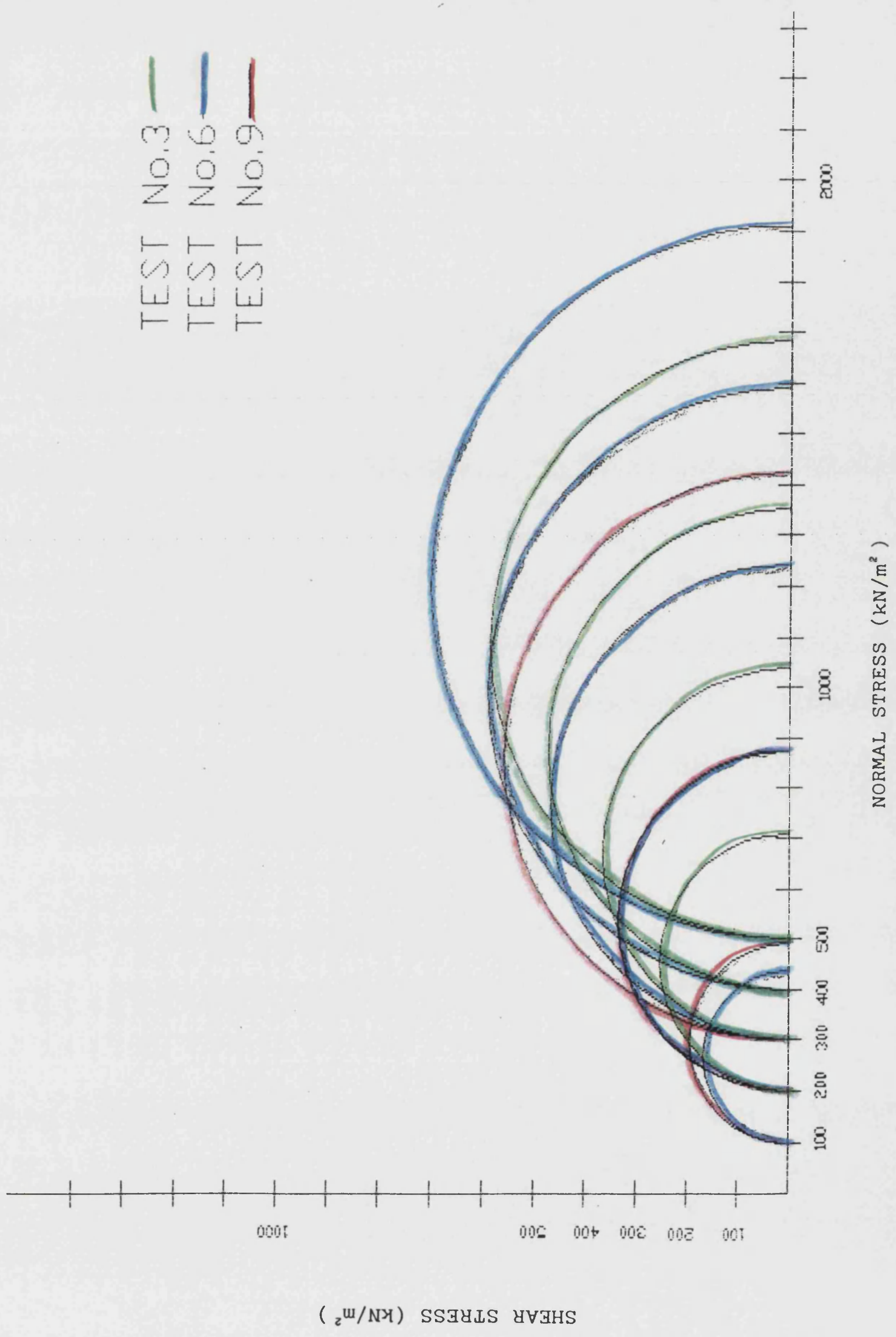


Figure 8.11c Combined Mohr circle plots for 'coarse' grade samples.

8.3.5 Discussion of Results (1st stage)

Considering first the different types of material. The medium Holm sand gives consistently higher values. The spread in values between the materials do tend to overlap, but the trend is clearly visible. This is not unexpected, since the grading curve for the Holm sand indicated a greater mix of sizes, therefore giving a sample with fewer voids and greater interparticle contact. Within each sample size the finer sand gave the lowest values. Again, not unexpected, as it is common practice to test only the fines content of mixed granular fill in order to determine a conservative value for design purposes. The course material shows a spread broadly similar to that for the medium sand.

Moving to comparisons between sample sizes. The most evident feature is the clear disparity between the 38mm results and those from the larger cells which are in close agreement. The smaller samples give consistently lower values. This is intriguing, since one would be tempted to suggest that the relative size of particle to sample size was the cause, although the upper particle size is well within the size limits quoted in section 8.2.2. An increasing number of papers are being published concerning the effects of the containment of soil samples within laboratory equipment, and the resulting effects on the determination of material parameters, specifically related to cone penotrometer and pressuremeter tests, Schnaid,F. & Houlsby, G.T. (1991). Numerically much of this work utilises cavity expansion theory in explanation. From this and previous literature, the proximity of boundary effects would be expected to increase the apparent strength of the sample, not decrease it. As explained earlier, small changes in density can have a major impact on material strength. A simpler explanation may well be that the smaller sample size inhibits the formation of dense samples of a uniform nature, thus allowing weaker areas to be present. This would link with those papers referred to above, in which there is agreement that dense samples are most affected by the proximity of a boundary surface. If this is consistently true, then the same effect should be visible when larger material is tested in the 100mm cell compared with the 254mm samples. Further tests at lower relative density would allow further comparison.

The two larger cell sizes are in broad agreement, with almost complete matching of some of the Mohr circle plots. Of further interest, the 254mm samples gave consistent results within each multistage test, resulting in less ambiguity in the value of friction angle for each test. Given the more complicated arrangement for the larger cell, the greater work involved in preparing samples, etc., it was feared this could lead to less consistent results. In the event, it did not. A further point to consider, and briefly touched on earlier, was the efficency of the friction free ends in the 254mm samples. These were found to be not fully effective in that following dismantling of the cell, barrelling of some of the samples was apparent which indicates friction at the end plattens. If this barrelling was significant, then with the low height:diameter ratio used within the large cell, higher apparent strengths would result. The very close agreement for the friction angles determined between the 254mm and 100mm samples suggests that there is little evidence of end effects affecting the results.

The results were encouraging and useful experience was gathered, but it was felt that further tests should be performed to clarify the aspects raised.

8.3.6 Calibration testing (2nd stage)

In order to take on board some of the issues raised from the 1st stage tests, and also to continue the comparison of the effect of particle size between different sample sizes the material selection for the 2nd stage tests was altered slightly. Two gradings were selected from those detailed in section 8.1.

(1) the course Leighton Buzzard calibration sand - section 8.1.1

(2) the 1 to 2mm material seived from the limestone grit - section 8.1.2

The testing methods and apparatus were identical to that described for the 1st stage tests, with the inclusion of some single stage testing to allow comparison. The tests were concentrated between the 38mm and 100mm cells, the 100mm already having shown good correlation with the larger cell. This decision, whilst not wholly satisfactory, greatly increased the number of tests that could be carried out, as the complexity and time required to set up the 100mm cell was much reduced in comparison with the 254mm cell.

8.3.7 Results (2nd stage)

Full result sheets are included in appendix 5, and are summarised in table 8.3. The tests have been organised by cell size, density, material type and where interesting comparisons occur between multi and single stage tests these have been separated.

Cell Size	Material	Density	Friction Angle	Comments
38 †	Cal.Sand	high	35 - 37	Both multi & single stage tests
		med.	35 - 36	
		low	35	
100	Cal.Sand	high	34 - 36	multi stage tests
		med.	34 - 35	
		low	33 - 34	
100	Cal.Sand	high	38	single stage tests
		med.	37	
		low	35	
254	Cal.Sand	med.	35	single
100	Type (2) 1 - 2mm grading	high	42* - 44	multi stage tests
		med.	40* - 43	
		low	40* - 43	
38 †	Type (2) 1 - 2mm grading	high	40* - 44	multi stage tests
		med.	38* - 44	
		low	39 - 44	
38 †	Type (2) 1 - 2mm grading	high	42	single stage tests
		med.	43	

† some of these tests were run with the drainage line closed, although the vacuum had been removed.

* indicates the final stage value(s) if clearly identifiable.

Table 8.3. Summary of 2nd stage calibration tests

8.3.8 Discussion of Results (2nd stage)

Dealing first with the calibration sand material. These tests showed good consistency between both sample sizes, with the friction angle increasing with density. There was very close agreement in the values for the friction angle determined. There was some disparity between the single stage and multi stage tests on the 100mm samples. The same general trend of increasing friction angle with increasing density was still apparent. But the actual values determined from the single stage tests were consistently larger than those resulting from the multi stage tests. There is a tendency when running multi stage tests to increase the cell pressure at the first sign of a leveling off of the load response curve, which may result in the cell pressure being increased too early. This would be a possible explanation of the data, leading to the conclusion that the single stage values are more reliable, although, as stated, there was good agreement between the multi stage tests from both 100mm and 38mm samples. Fewer single stage tests were carried out on the 38mm sample which limits comparisons, but those that were done fell within the range of the multi stage tests. If the single stage results are considered to be more reliable then again the smaller cell is seen to give lower values than the 100mm.

The results from the tests on the chippings are less clear. All the tests indicate that the material yields a higher friction angle than the finer calibration sand. There is a wide scatter with the range of values within the various density bands overlapping considerably. Looking at the maximum values within the various density bands, a general rise in the value for the friction angle with increasing density is evident. The values from the single stage tests from the 38mm samples fall below or within the range of values for the 100mm cell, again indicating lower values coming from the smaller samples.

A more detailed parametric study into these effects seems to be indicated. It was decided to progress onto the testing using the large cell to continue the investigation to the larger grained material, and also to further elaborate on the operational characteristics of the larger cell.

8.4 STATIC TESTING OF LARGE GRAINED MATERIAL

These tests were run for a number of reasons. Firstly to continue the pattern of the earlier tests to see whether any clearer relationships emerged. Secondly to determine the operational characteristics of the large cell when dealing with large grained material, also the supporting control and monitoring equipment. Lastly to provide material data for the larger particulate material for later use in the graded and cyclic experiments.

The materials utilised from those detailed in section 8.1.2 were the two largest gradings available;

(1) 10mm nominal grading

(2) 20mm to 30mm nominal grading.

As previously noted, these had very angular particles.

As the loads for this material were expected to exceed those for the finer grades already tested, and also to allow a greater range of cell pressures to be examined, the 50 kN digitally contolled actuator was replaced with a 100 kN manual hydraulic jack. The load was monitored by two independant load cells, one giving a direct digital readout. Displacement measurement utilised a strain gauge displacement transducer bearing on the cell ram top plate. All the electrical transducers were logged by the ADU.

The controling software for the ADU allowed real time screen plots of the logged channels against time. This facility was used to provide the load response curve for the sample as the test was running, allowing decisions to be made regarding the progress of the test. These plots were later screen dumped to the printer and formed part of the data output for each test. Load, stroke, and time channels were all logged, allowing XY plots of load versus stroke to be produced once each test was completed. Additionally, a full print out of all logged data was provided in order to calculate the stress levels required to determine friction angles.

8.4.1 Mode of Testing

The use of a manual hydraulic jack meant that a constant rate of strain could not be maintained. The tests were run by use of the real time load response curve of the sample. This gave sufficent information with which to judge the continued load application.

The general arrangement of the apparatus and the sample preparation procedure have been detailed previously.

Considerable problems were encountered during these tests with the membranes. The highly angular nature of the materials resulted in many instances of the membranes tearing, especially at the higher confining stresses, resulting in a loss of cell pressure and premature failure of the sample. The use of thicker membranes was an obvious solution, however considerable difficulty was encountered in stretching the 254mm diameter membranes over the 304mm outer former, top and bottom plattens of the cell. The use of additional membrane protection, allowing the thinner membranes to be used, was therefore investigated.

Initially a layer of fabric was placed against the inner, sample face, of the membrane, so that any indentation by the granular particles would be reduced by this layer of fabric. The fabric was split into two vertical overlapping elements inorder to allow relative movement between granular particles, fabric layer, and outer latex membrane, thus reducing any additional restraining action this 'protective' layer may impose upon the sample response. Whilst the principle was successful, this application was not. It was found that as the sample deformed, the particles would displace the fabric from the sample ends at the top and bottom plattens, and again pierce the membrane. To provide secure protection around the top and bottom plattens a couple of membranes were cut into shorter lengths. These shorter lengths were placed on the inside face of the sample former, one at either end sandwiching the inner layer of fabric. This arrangement effectivly gave a double thickness membrane around the top and bottom plattens. Whilst this arrangement protected the membrane, it was found impossible to form a sample with perpendicular sides adjacent to the plattens, due to the inability to pull back the loose inner section of membrane evenly. The final solution to this problem was to use two additional split rings of the fabric material, bent and cut to allow relative movement, placed around the top and bottom of the sample former, thus overlapping the main protective elements, preventing any weak spots appearing. This membrane protection is illustrated in plate 8.3.

8.4.2 Results

All the test data is held in appendix 5, and summarised in table 8.4. Only those tests that ran to completion are included. Tests with membrane failures prior to sample 'failure' have been discarded.

Material	Confining Pressure	Friction Angle	Density kN/m^3 *	Test No.
10mm	2 Bar	42	14.26	6
	2.5 Bar	38	14	2
	3 Bar	38 - 41	13.85	7
	3.8 Bar	34	14.15	3
	4 Bar #	34	14.21	4
	4 Bar #	35	13.63	5
	4 Bar ‡	39	15.33	8
	1 Bar ‡	44 - 46	15.10	10
	1 Bar ‡	49	15.08	11
	1 bar †	45.5	15.2	12
20 - 30mm	1 Bar ‡	45 - 51	12.37	13
	2 Bar ‡	40 - 45	12.71	14

‡ Samples tested with membrane protection

† Cell pressure increased during test. Friction value Calculated on basis of extending original data line. Pressure jump clearly indicated on graphical output.

* Based on Nominal sample volume. See discusion.

\# Membrane failure, but 'peak' resistance apparently attained.

Table 8.4. Summary of Large scale testing

8.4.3 Discussion

The first point to note is the low densities achieved during these tests. The samples were formed by the single pour technique from a constant height to achieve a uniform density. The higher densities for the latter tests on the 10mm gravel, coinciding with the use of membrane protection arose for the need for greater care in the placement of the material to avoid disturbance of the membrane protection. The density calculations utilised the nominal sample volume, but as previously mentioned, membrane indentation with large grained material does reduce the actual volume of the sample. The values given are therefore useful for comparison purposes only.

Interpretation of the data must take account of the inconsistent operation of the friction free ends. A noticeable stiffening of the sample, represented as a discontinuous 'jump' on the load response plot, was apparent as the axial strain exceeded ≈ 10% if the friction free ends did not operate smoothly. This clearly indicates that for the large grained material the combination of a low height:diameter ratio and friction at the end plattens influences the sample response. In order to extract some data from those tests affected, the form of the load response curve prior to the stiffening was extended to see if sensible values resulted. Additionally, values for the friction angle were determined at 10% strain. This allowed comparison between tests that showed 'peaks' at higher strains, which would have been more affected by end effects. Care must be exercised during this type of data manipulation and in the use of the resulting information. There is a tendency to be selective in the use of data giving rise to false conclusions. With the limited number of tests conducted, overall trends, if apparent, are more robust.

The influence of the frictional constraints at the end plattens is more noticable at the lower confining pressures, accounting for the higher friction angles. As the confining stress increases the friction angles become more consistent.

Comparing the results between samples with and without the membrane protection, those with the protection indicate higher values for the friction angle. However, the greater care needed in placing the material when utilising the protection gave rise to higher densities. These higher densities would increase the friction value. It is the authors opinion that the membrane protection does not influence the result to any great extent. Further testing is required to fully justify this assertion, but is hindered by the sticking 'friction free' end plattens. Failure of the membranes without protection hinders comparative testing at the higher cell pressures. Conducting future tests with the protection at a variety of densities would prove satisfactory and allow comparisons.

8.5 CYCLIC TESTS

These tests were necessary to validate the testing configuration for the large cell. These tests required the full set of data monitoring devices, including strain rings, LVDT's, and outputs from the control cabinets. The sample preparation procedure incorporated the location studs and specially prepared membranes. All these items have been described in sections 6 and 7.

As discussed in sections 6.1.1 and 6.2 it is advisable to measure the load within the cell chamber so that effects of friction on the ram/bush interface are removed. This is especially the case for low stress/strain applications. Ideally, for dynamic tests the load cell should be placed in a static position relative to the sample and loading ram so that inertial effects are minimised. Beneath the base of the sample or lower pedestal would be a suitable position. The present configuration of the large cell does not incorporate an internal load cell due to cost constraints. This limits the application of the apparatus for dynamic testing to higher stress/strain ranges such that frictional effects become minimal. Kokusho (1980) demonstrated that even if the frictional effects were accounted for when using an external load cell, the results for shear strains below 10^{-4} still contained an appreciable error.

The inconsistent operation of the friction free end plattens was a factor also requiring attention. A further modification was the addition of a 1.27mm. thick layer of latex rubber - identical to that of the membranes - placed at each end of the sample. This system has to date proved unsucessful. Limited time due to the extended program of calibration tests has constrained efforts to provide an adequate solution to this problem.

A number of cyclic loading tests have been carried out with the apparatus in its present configuration. These are useful for verification purposes, both of procedures and equipment, and are reported here for the information they provide for the development of the apparatus.

The arrangement of the sensors around the sample has been discussed previously in section 6.0 and illustrated in plates 6.2 and 6.3. The overall configuration is illustrated in figure 8.12.

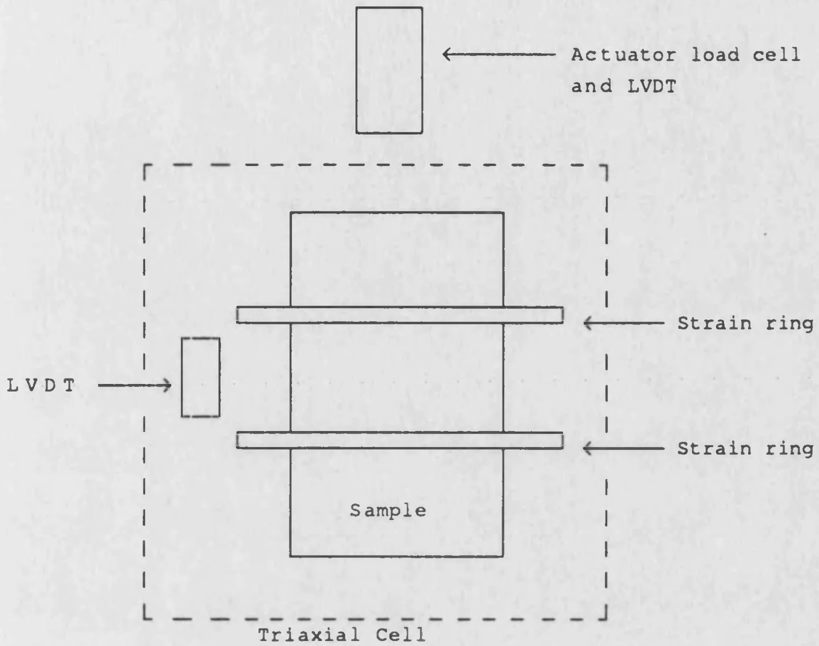


Figure 8.12. General configuration for cyclic tests

Initially it was found impossible to hold the cell pressure. This was due to leakage of pressurised water into the sample at the junction where the location studs pierced the membrane. It proved difficult to compress the 'O' ring seal a sufficient amount without tearing the membrane. Two possible solutions to this problem were considered.

(1) Use of a double membrane. This would still require holes in the second, outer membrane. Difficulties would arise preparing the sample as only one membrane can be pulled via the vacuum.

(2) Use of a flexible sealant around the junction of the location stud and membrane. Such a sealant would need to be inert relative to the latex membrane.

Option (2) was selected as the most apropriate solution. Utilising a one part silicone sealent ARBOSIL 1081, manufactured by Ratcliffe & Co. Ltd, proved successful. The sealant was placed around the location studs on the external face of the membrane, and is shown in operation in plate 8.4.

The material utilised for these tests was the nominal 10mm grading. Membrane protection was used to allow testing at high cell pressures. Great care needs to be taken during the assembly phase in order not to disturb the sensor arrangement. The remote instrumentation provides the only information regarding the sample whilst the test is in progress since it is not possible to visually examine the sample until the apparatus is dismantled.

Full copies of the relevant test data are included in Appendix 5 for reference. Sample plots are shown in figures 8.13 to 8.15 and discussed below.

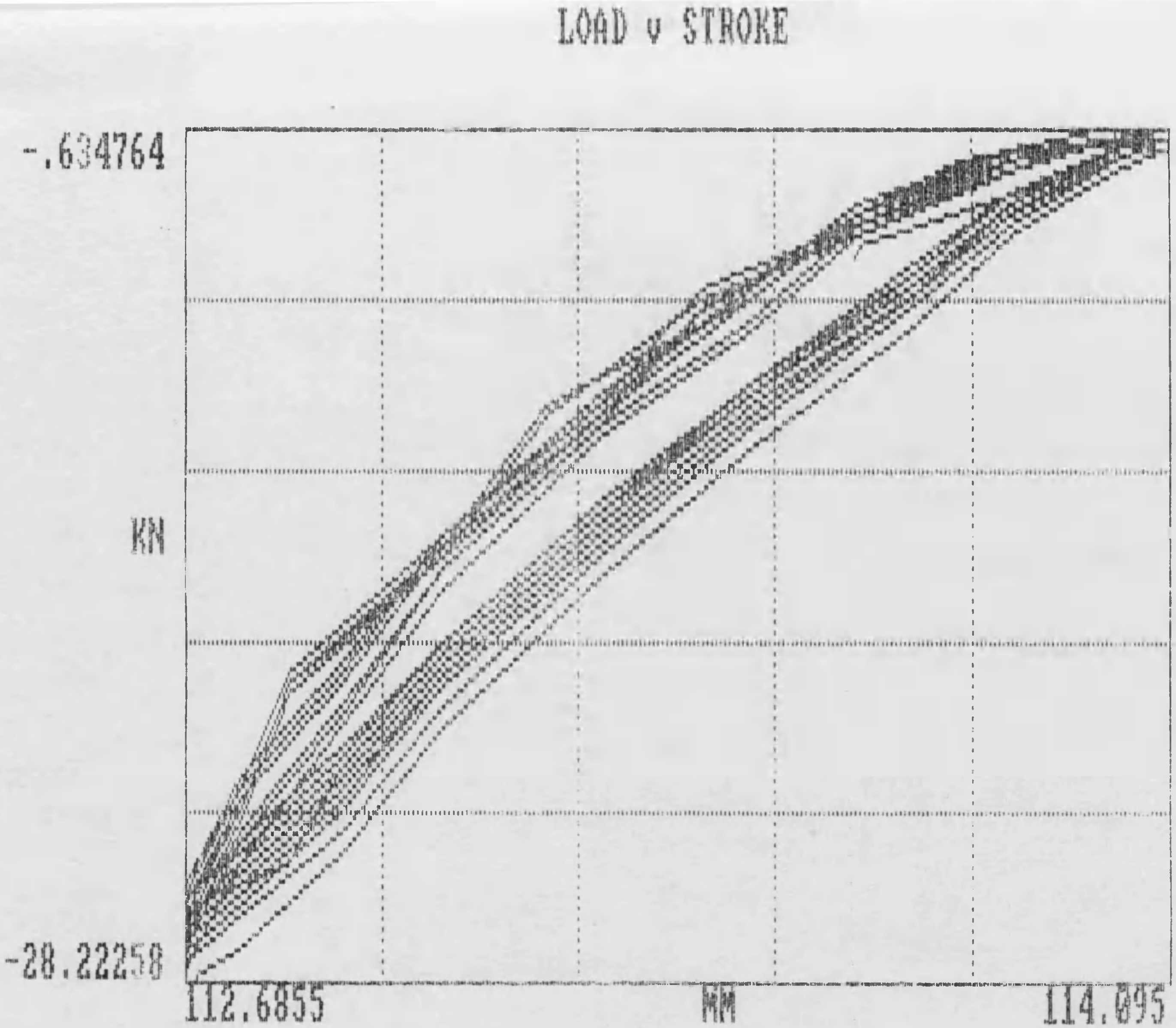


Figure 8.13. Sample load vs stroke plot for dynamic verification test 6.

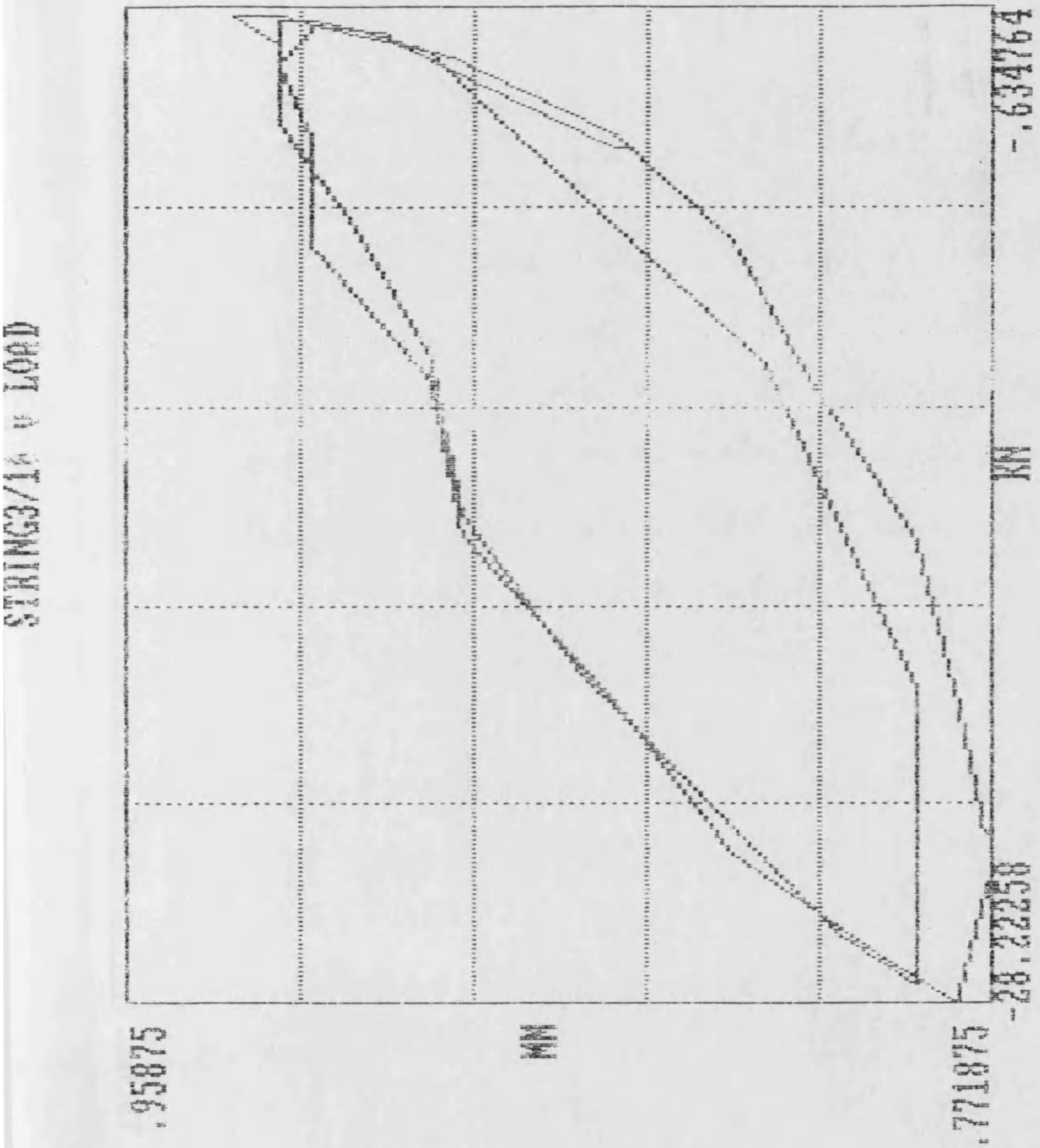


Figure 8.14. Sample plot of strain ring response vs load from dynamic verification test 6. First 2 cycles shown.

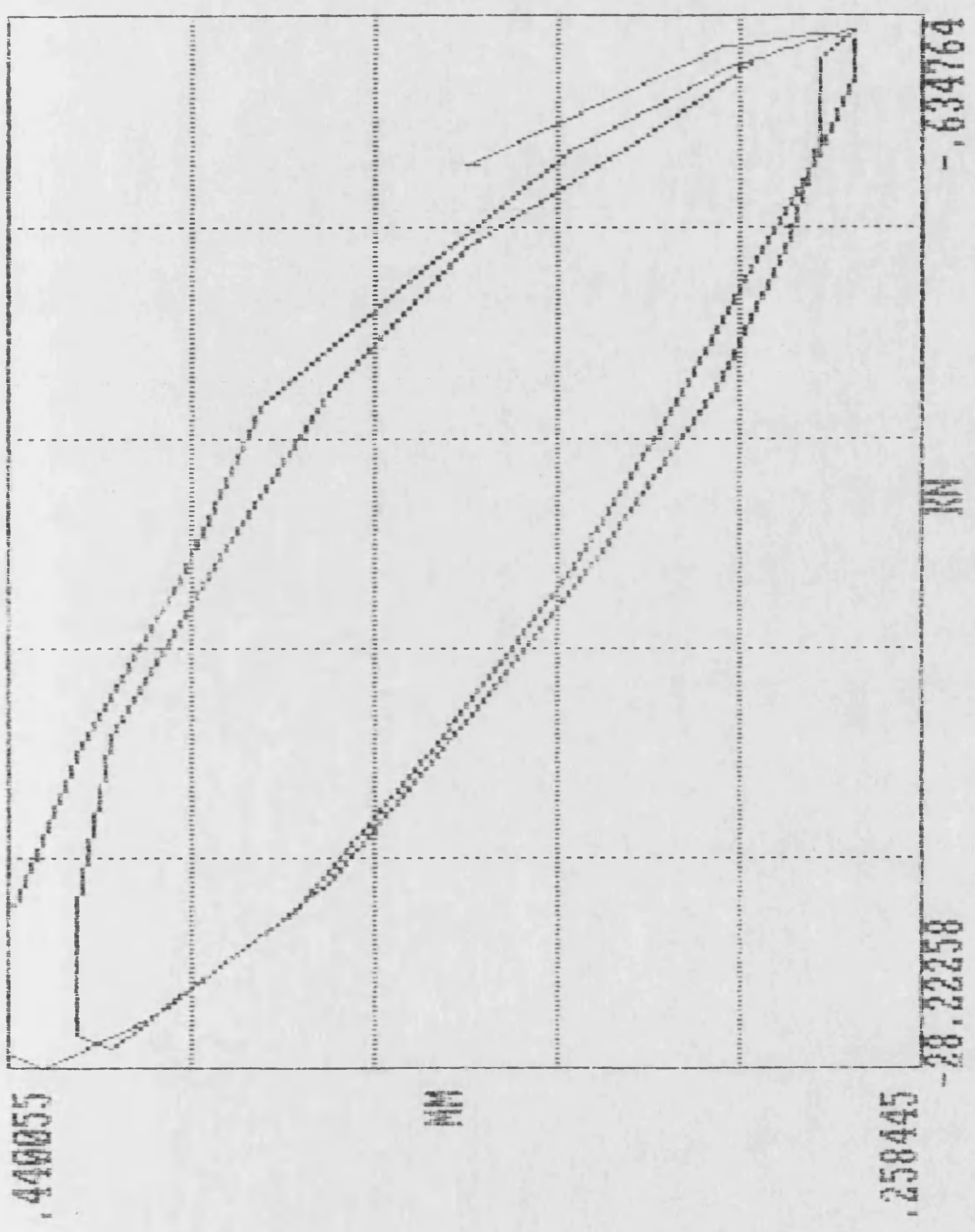


Figure 8.15. Sample plot of strain ring response vs load from dynamic verification test 6. First 2 cycles shown.

The hysteretic nature of the stress - strain response is clearly evident. The response as monitored by the external sensors in shown in figure 8.13, and is matched by the output from the strain rings as indicated in figures 8.14 and 8.15.

The output from the strain rings was variable. This is attributed to a number of factors. The strain rings were originally tested placed vertically between location studs held firmly in hydraulic jaws. Within the triaxial cell they are placed horizontally relying on the embedment of the location studs for a secure fixing. The strain rings are susceptible to very slight movements and require a firm support that reflects the sample movement. The depth of embedment of the location studs required for a particular test, is dependent on the nature of the material under test, angular or rounded, and also on the particle size distribution, single sized or graded. In order to ensure a rigid support it is necessary to provide longer location studs for the larger particulate material so that the stud is gripped firmly in place. It is recommended by the author that this anchorage length needs to be at least 1.5 x minimum particle size diameter. This places the current studs on the border for the 10mm material, and would explain why some became displaced.

It is important that the design of the location studs and fixings for the strain rings reflects the deformation of the sample accurately, especially at the very low strains (10^{-6}) required for the determination of G_{max}. Within the current setup the strain rings have been shown to be capable of detecting radial strains within the range 10^{-4} to 10^{-3}. From the experience gathered to date, it is the author's opinion that this is approaching the limit of accuracy for the combined components of this system when used for monitoring cyclic tests. To assess the response at lower strains non - contacting transducers are favoured. Such a system would not require mechanical fixings subjected to load/ displacement reversals giving greater confidence in the repeatability and accuracy of the output.

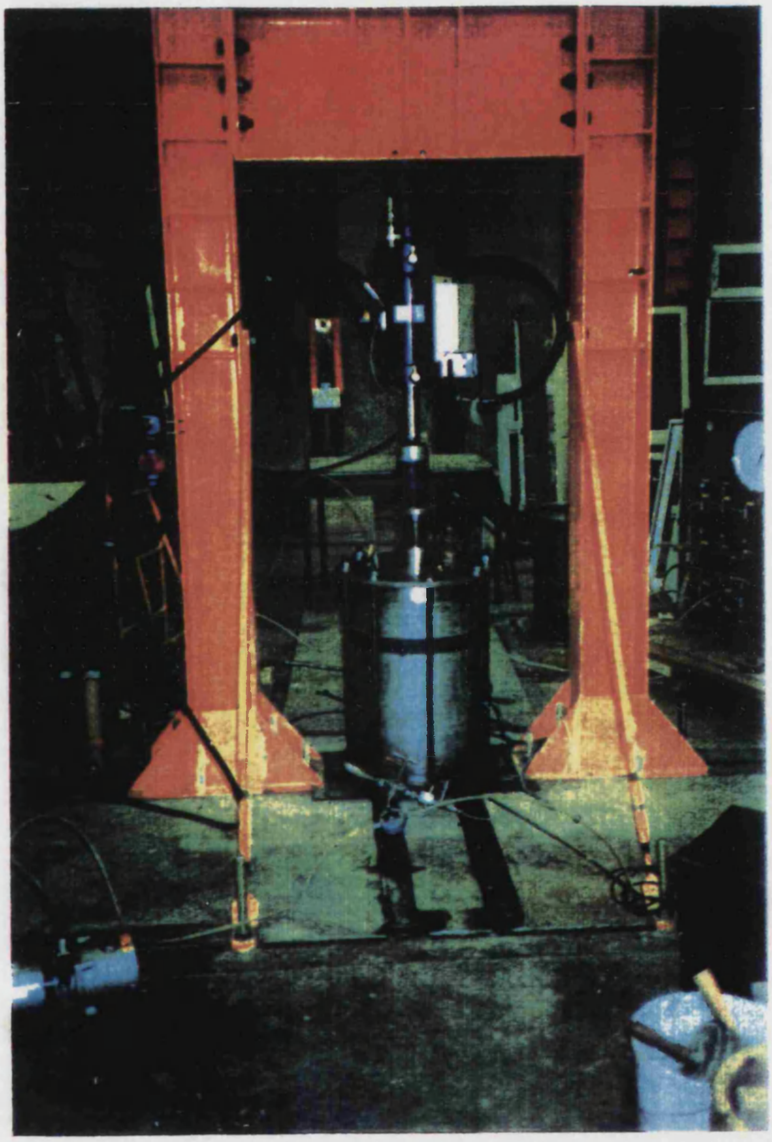


Plate 8.1 Large cell in placed within load reaction frame on the strong floor. The greased track can be seen extending away from the frame. This plate shows the 50kN fatigue actuator in position.

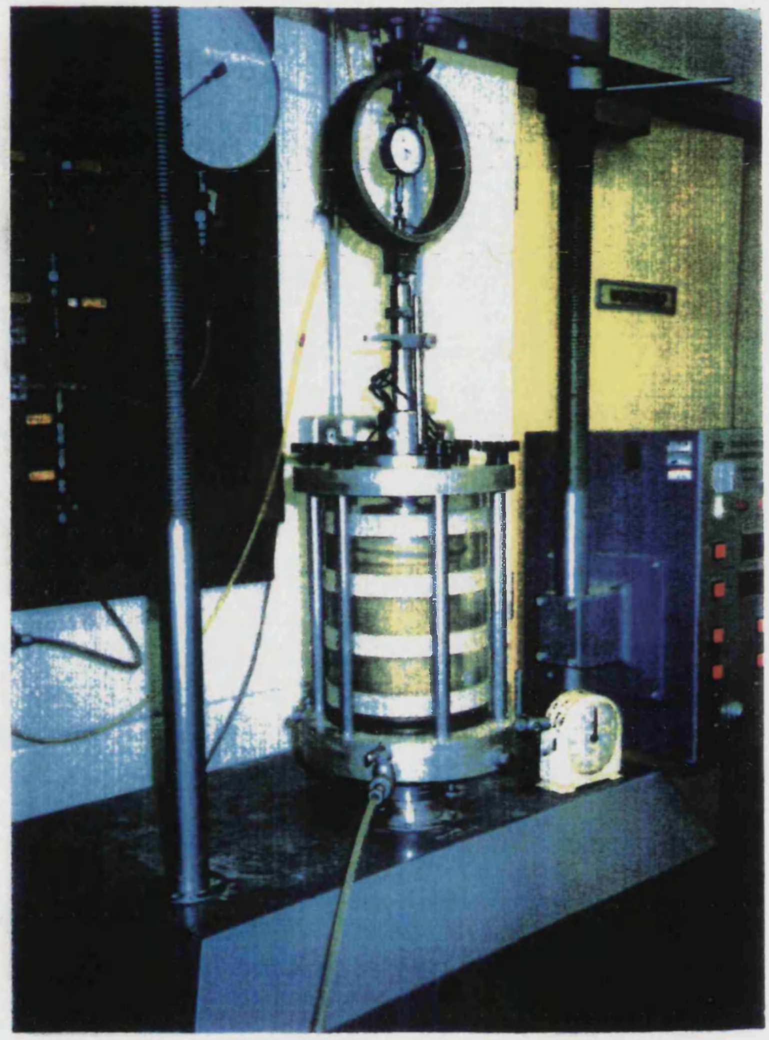


Plate 8.2 100mm cell assembled in 10 tonne loading frame showing proving ring arrangement. Cell pressure is being applied but the sample vacuum is yet to be released.

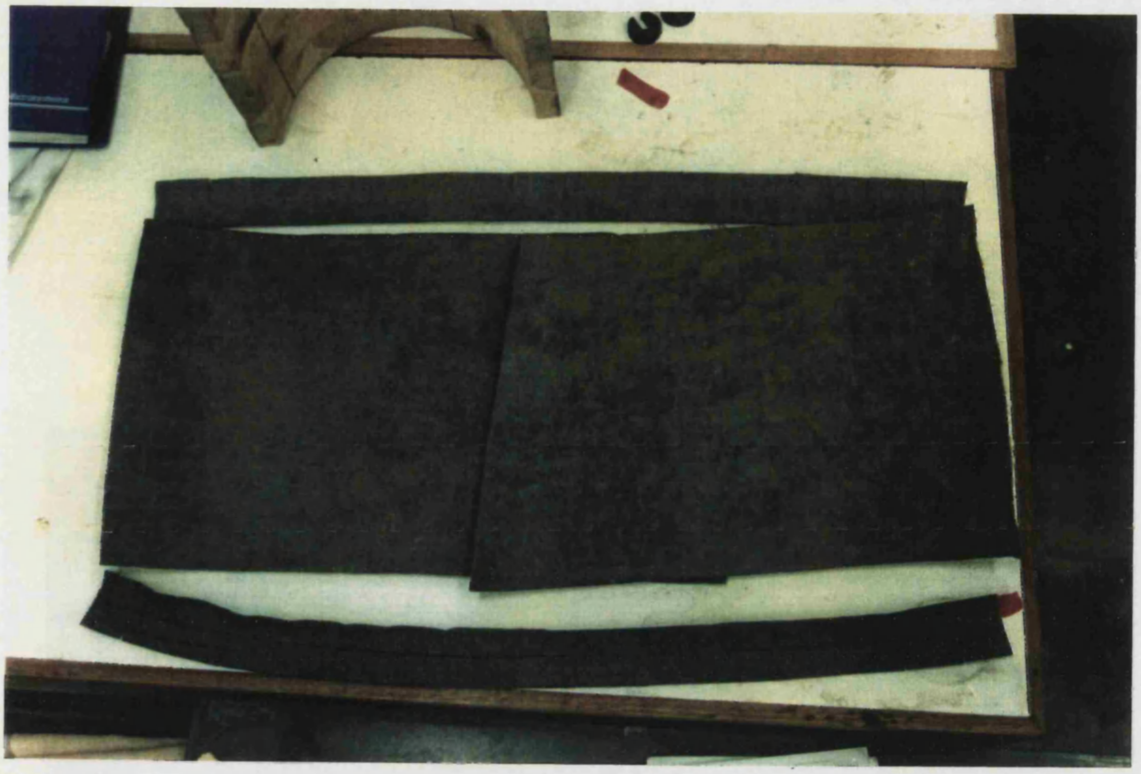


Plate 8.3a This shows the individual elements of the membrane protection utilised when testing the large grained material in the 254mm samples.

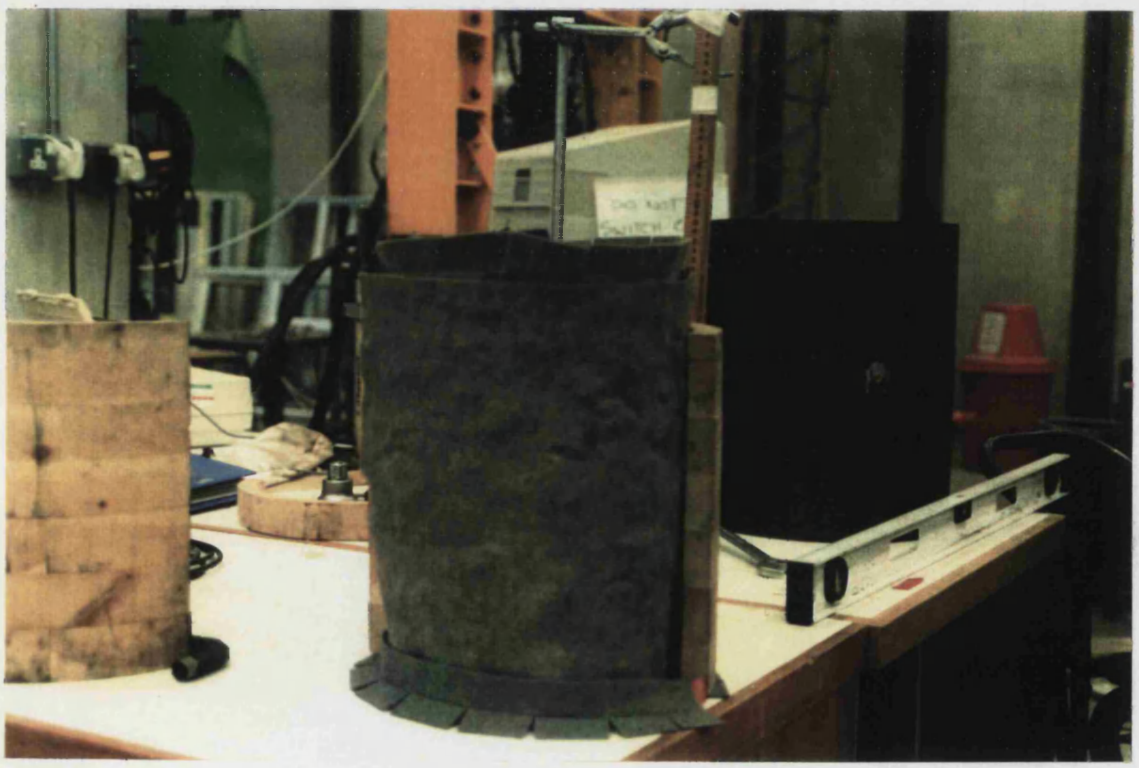


Plate 8.3b The membrane protection in the 'erected' form as placed against the inside face of the membrane.

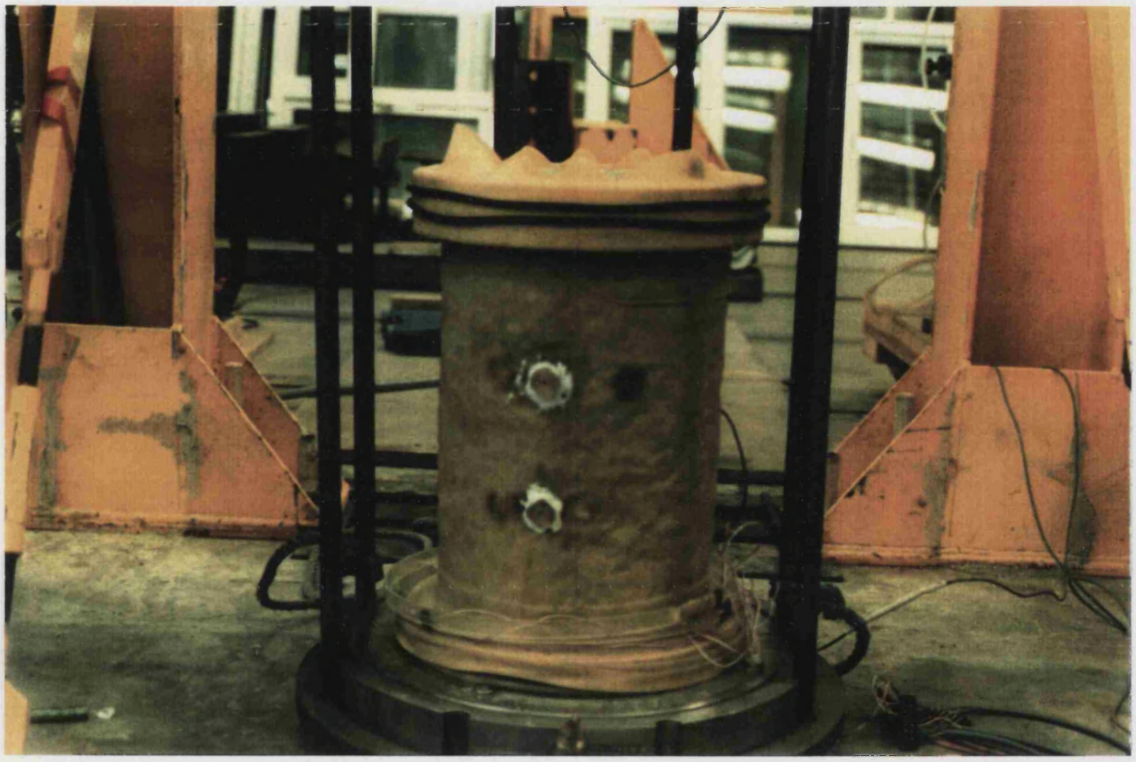


Plate 8.4. Sealant around location studs.

9.0 CONCLUSIONS AND FUTURE WORK

This chapter brings together the results of the work completed to date, and puts it into context with work planned for the future.

9.1 CONCLUSIONS

A large scale triaxial apparatus capable of holding samples up to 304mm in diameter has been brought into operation with all the associated control and monitoring devices required for a range of both static and dynamic testing regimes.

The procedures required to form large samples of particulate material on a regular basis have been perfected, and problems of membrane penetration associated with the testing of large angular particles have been solved.

The principle of utilising large 'strain rings' to measure the radial expansion of soil samples has been investigated. The interpretation of the resulting data is complicated by the inherant damping within the monitoring system and security of the location studs. Alternative non contacting displacement transducers are recommended.

The decision to limit the overall axial dimension of the apparatus, thus limiting the diameter:height ratio of the larger samples, though unavoidable and believed acceptable at the time has proved troublesome. The friction free ends utilised to date have proved to be inconsistant. Working friction free end plattens have been reported as early as the 1960's, e.g. Bishop and Green (1965), although on much smaller samples. However, Hettler and Valdoulkis (1984) have reported success on their large oversquare rig using ground glass elements. This would not seem therefore to present an insuperable problem, but was beyond the resources of this current work. However, it should be noted that the reported successful usage of friction free end plattens in the past has related to static testing.

Tests on a range of sands and chippings has shown that consistant results can be achieved from 254mm samples with a reduced height:diameter ratio when compared with 100mm samples of traditional sample dimensions.

Comparable tests between the 38mm, 100mm, and 254mm samples on a range of material from fine sands through to fine gravels, indicate that the 38mm samples give consistantly lower values for the angle of friction. This is of particular interest, as the opposite would be expected due to end effects and ratio of sample dimension to particle size. The majority of comparable testing to date has utilised high relative densities and it is suggested that this effect may be due to the small sample diameter relative to the particle size inhibiting the formation of dense samples. Further comparable testing at lower relative densities would shed further light on this aspect.

In terms of the overall objectives of the project, the further investigation into the scaling effects of different sized samples, though necessary for the long term interpretation of the dynamic tests, deflected effort from the development of the large cell and procedures for the dynamic testing itself.

9.2 FUTURE WORK

The new large scale triaxial apparatus described in this work provides a sound basis for development and the incorporation of a variety of sensors that would both simplify and increase the efficiency of the testing. The use of a load cell within the triaxial cell is essential for low stress/strain applications and dynamic testing. Utilising non contacting displacment transducer technology would significantly enhance the repeatability and accuracy of measuring the sample deformation.Increasing the overall dimensions of the cell to allow the use of 'normal' sample diameter:height ratio's would alleviate the need for friction free end plattens. The design of the apparatus would easily accomodate this change, requiring a longer 'tube' element and new tie studs. Manufacturing considerations would need to be considered if this option was followed. Forming samples this size would be a laborious and time consuming task, requiring extreme care to ensure consistent samples.

In terms of the testing itself, additional comparisons between the 38mm and 100mm cell are required at low and medium relative densities to further examine the phenomenon of the smaller samples giving lower values for the friction angle.

The review of previous work in section 3, gave conflicting reports on the relationship between damping and relative density for large grained particulate material. Investigation would provide more information on the matter, allowing a consistent comparison between the previous work. That too, was carried out utilising triaxial cells, and thus the proceedures for extracting damping values would be consistent, avoiding the use of dissimilar numerical models and eradicating a possible source for the spread in damping values previously reported.

From the experience gained it is recommended that the continuation of the dynamic testing, initially be persued on the 100mm cell. This would significantly reduce the sample preperation time and allow development at a quicker rate. Although the associated sensor requirements will be at a much reduced scale, itself introducing a new set of parameters requiring attention.

The large triaxial rig in its present configuration is, in the short term, more suited to continuation of the static testing. This would allow investigation into the validity of producing graded samples by shifting the grading curve down the size axis, and provide information on the scaling of graded samples between the different cell sizes.

As well as aspects of gradation, the effect of angularity also requires consideration. This needs to be looked at from both graded and single sized samples. It is to be expected that a single sized sample of highly angular material would have higher stresses at inter-particle contact points than a single sized sample of rounded material due to the fewer contact points, affecting both the stiffness and damping response. Such differences would be more noticable with larger grained material. These differences might reduce with graded samples as the amount of contact points increase and become more evenly matched. The larger cell provides the facility for these effects to be investigated.

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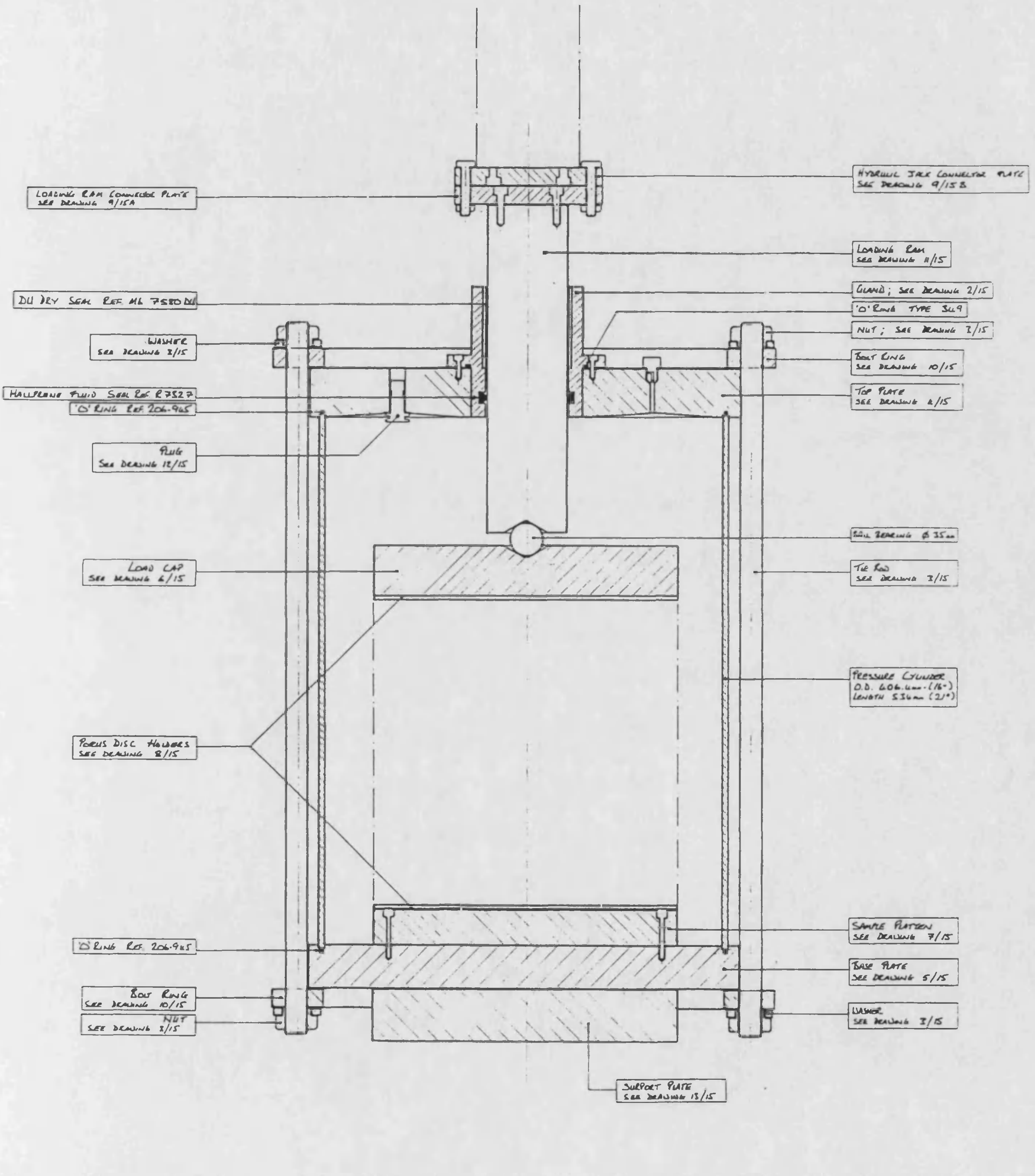
APPENDIX 1 Specification of Large Triaxial Cell

REF	DESCRIPTION	MATERIAL	O/A SIZE	QUAN.
1	PRESSURE CYLINDER	STAIN. STEEL	O.D. 406.4mm x 536mm	ONE
2	GLAND	STAIN ST.	Ø 160mm x 132mm	ONE
3	TIE ROD	MILD ST.	Ø 20mm x 715mm	EIGHT
4	M20 NUTS (RIGHT HAND THREAD)	MILD ST.	A.F. 37.95mm x 22mm	16
5				
6	WASHERS	MILD ST.	Ø 66.5mm x 9mm	16
7	TOP PLATE	STAIN ST.	Ø 466.5mm x 50mm	ONE
8	BASE PLATE	STAIN ST.	Ø 466.5mm x 40mm	ONE
9	LOAD CAP	ALUMINIUM	Ø 304.8mm x 50mm	ONE
10	SAMPLE PLATTEN	STAIN ST.	Ø 304.8mm x 30mm	ONE
11	PORUS DISC HOLDERS	ALUMINIUM	Ø 304.8mm x 3mm	TWO
12	HYDRAULIC JACK CONNECTOR PLATE	MILD ST.	Ø 167mm x 18mm	ONE

REF.	DESCRIPTION	MATERIAL	O/A SIZE	QUAN.
13	LOADING RAM CONNECTOR PLATE	MILD ST.	Ø 167mm x 18mm	ONE
14	BOLT RINGS	MILD ST.	Ø 494.5mm x 20mm	TWO
15	LOADING RAM	STAIN ST.	Ø 80mm x 324mm	ONE
16	DU DRY SEAL MB 7580 DU			ONE
17	HALLPRENE FLUID SEAL R7327			ONE
18	'O' RING TYPE 349		CROSS-SECTION 5.34mm	ONE
19	'O' RING TYPE 206-945		CROSS-SECTION 3.50mm	TWO
20	'O' RING TYPE 113		CROSS-SECTION 2.62mm	ONE
21	BALL BEARING	STAIN ST.	Ø 35	ONE
22	M5 SOCKET CAP SCREW	STAIN ST.	M5 x 35mm	FIVE
23	M5 SOCKET CAP SCREW	STAIN ST.	M5 x 30mm	EIGHT
24	M5 SOCKET CAP SCREW	STAIN ST.	M5 x 20mm	SIX

REF	DESCRIPTION	MATERIAL	O/A SIZE	QUAN.
25	M8 SOCKET SCREW	STAIN ST.	M8 x 25mm	16
26	M10 BOLT	MILD ST.	M10 x 50mm	EIGHT
27	M10 NUT	MILD ST.	NORMAL	EIGHT
28	BLEED VALVE	STAIN ST.	(M12) Ø 18mm x 17mm	ONE
29	PLUGS	STAIN ST.	Ø 19mm x 32mm	NINE
30	DOWTY SEAL 655-009-1576-91			ONE
31	'O' RING TYPE 012		CROSS-SECTION 1.78	NINE
22	SUPPORT PLATE	MILD ST.	Ø 304.8mm x 50	ONE
33	M5 SOCKET CAP SCREWS	STAIN ST.	M5 x 60mm	EIGHT



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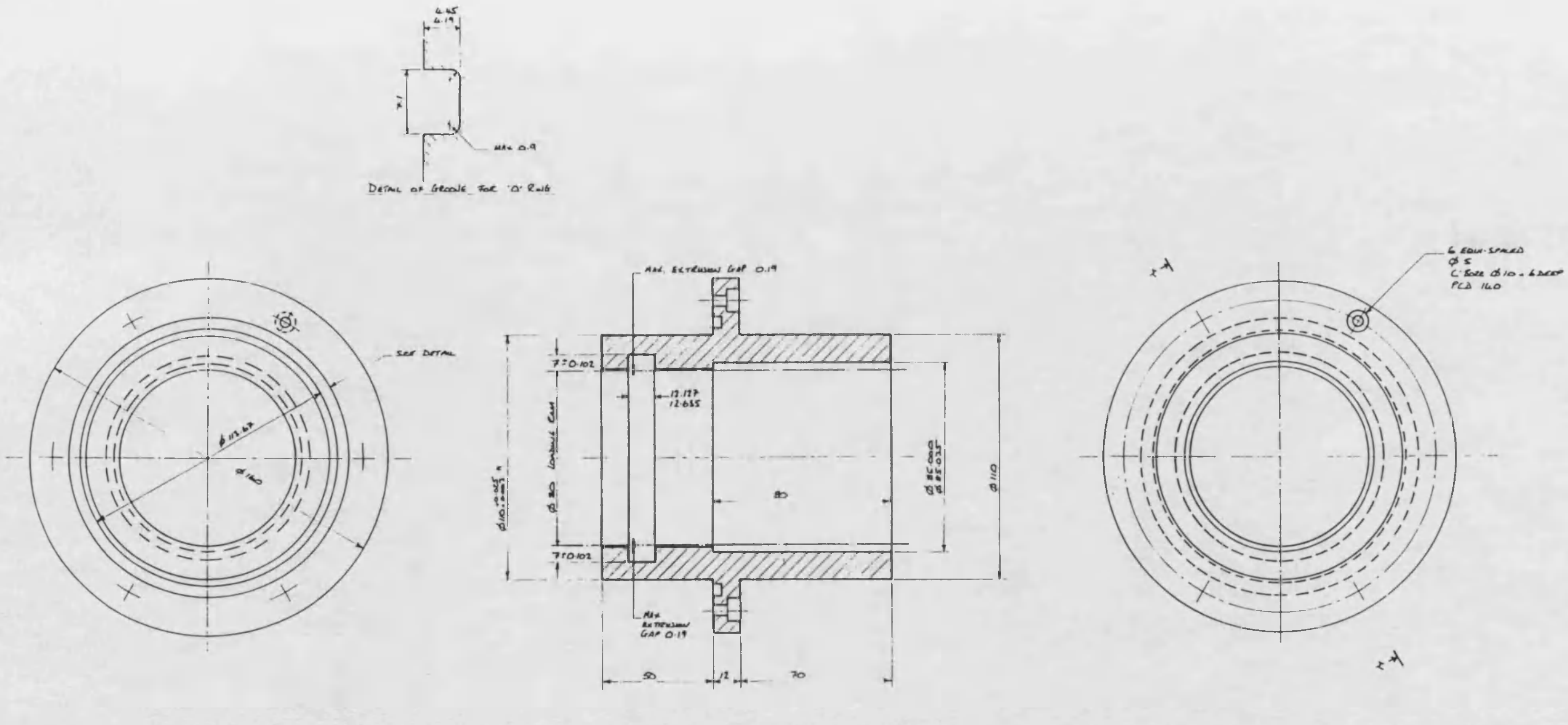

Section on X-X

* Transition fit H7 k6

All dimensions in mm unless otherwise stated

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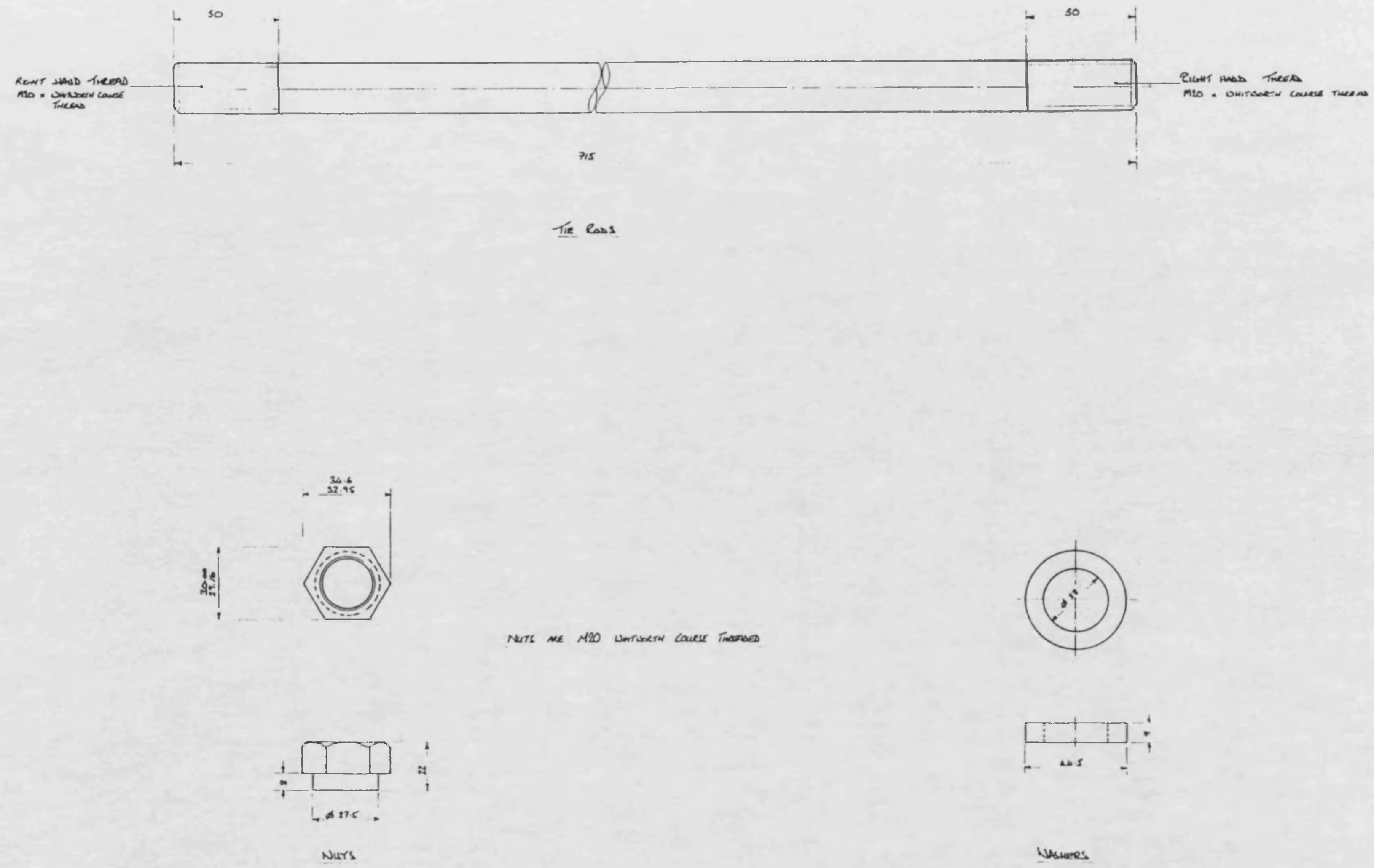
O/A Size : Ø160 × 132	Job Title : 12" Triaxial Cell
Quantity : One	University of Bath . Sch. of Arch. & Eng
	Scale 1:1
Do Not Scale off Drawing	Date 25/6/88 · Drawn by S.G.R. · Drwg. No. 2/15



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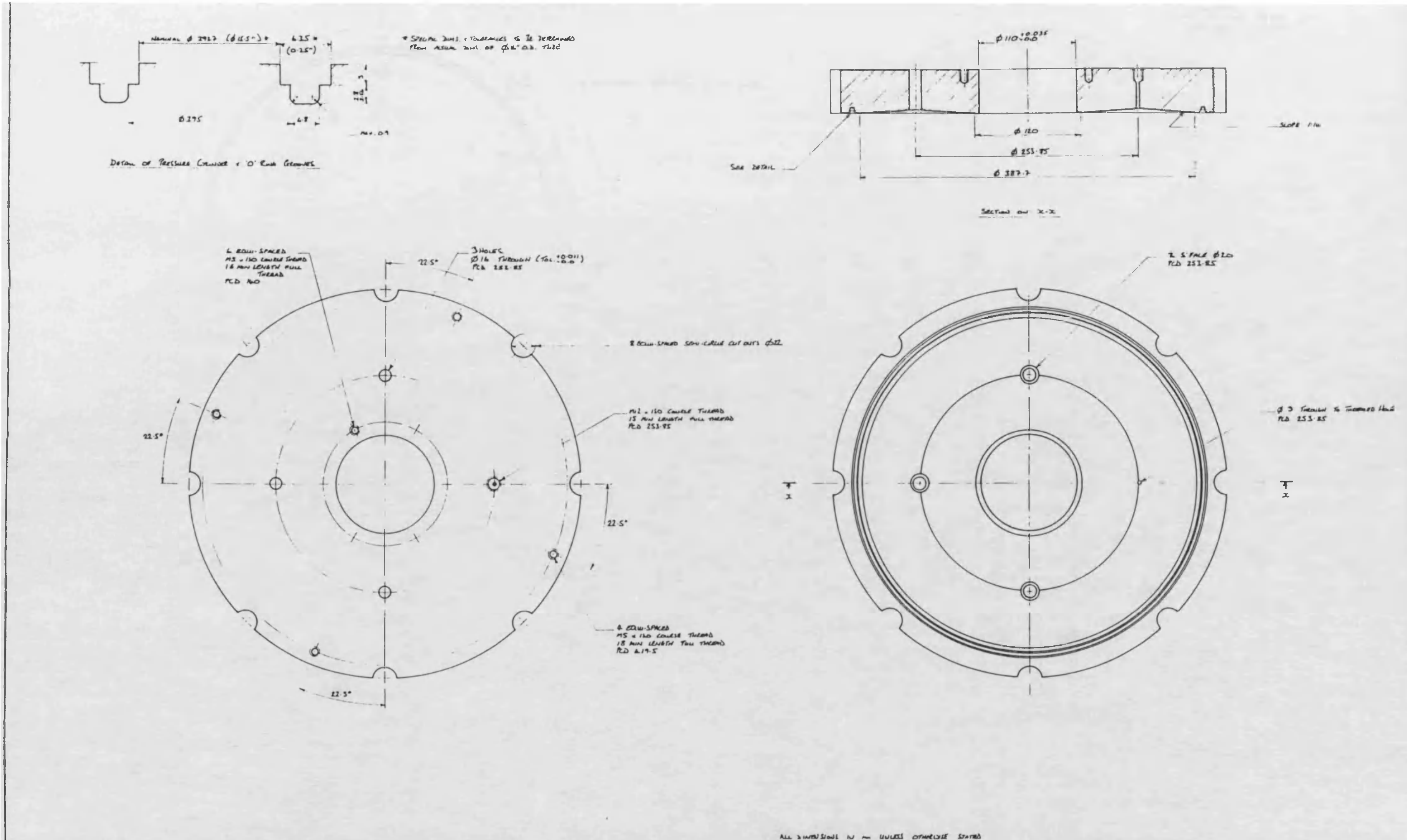
O/A SIZE: TIE RODS ⌀ 20 × 715mm ; NUTS AS SHOWN ; WASHERS ⌀ 44.5 × 9mm	JOB TITLE: R' TRIAXIAL CELL
QUANTITY: TIE RODS 8 (EIGHT) OFF ; NUTS 16 (SIXTEEN) OFF ; WASHERS 16 (SIXTEEN) OFF	UNIVERSITY OF BATH SCH OF ARCH & ENG
	SCALE 1/1
DO NOT SCALE OFF DRAWING	DATE 6/7/77 · DRWG. BY. E & R. · DRWG. No. 3/15



MATERIAL TYPE : STAINLESS STEEL
O/A SIZE : Ø 444.5 x 50 (Ø17.5" x 1.968")

QUANTITY : ONE

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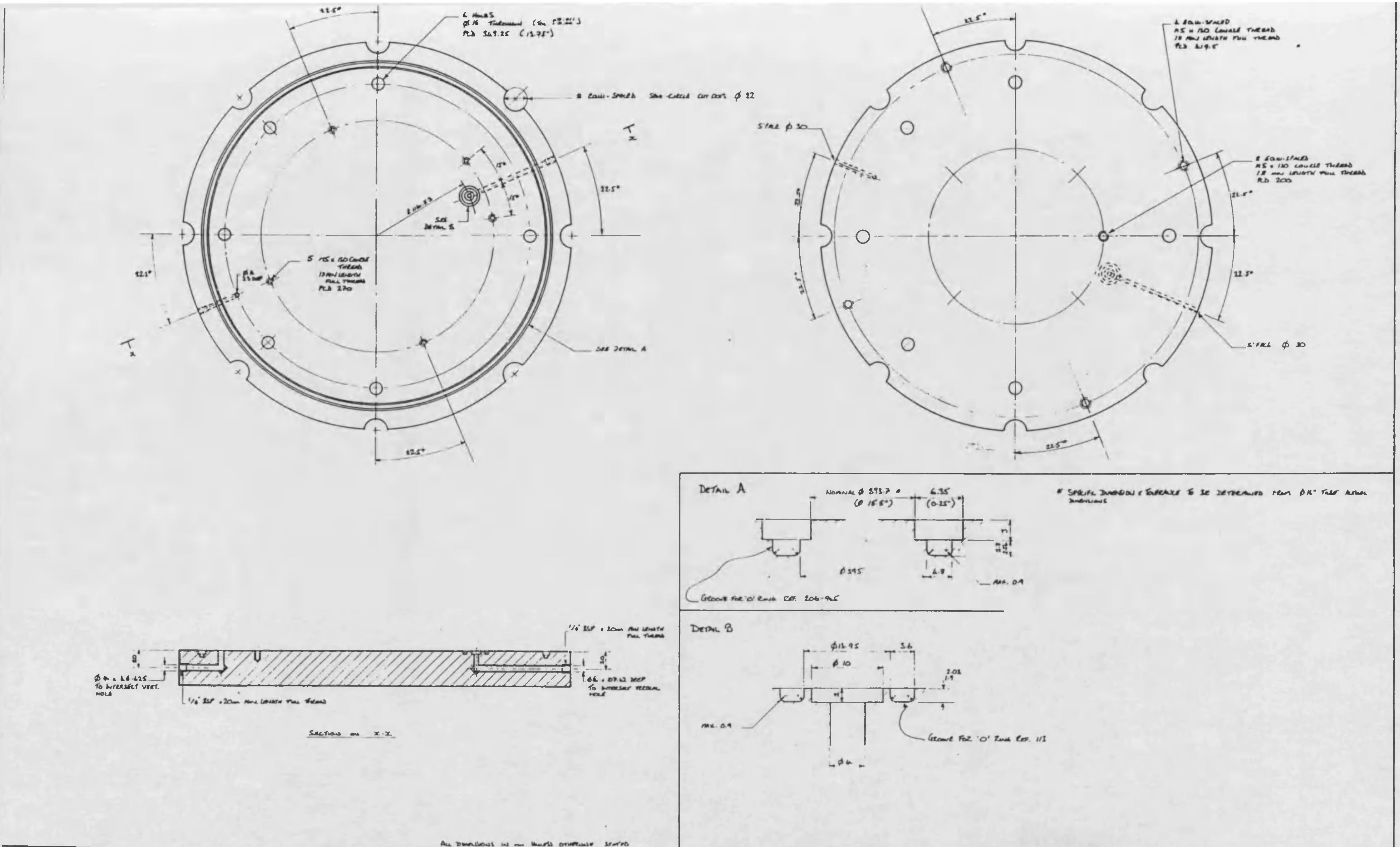

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MATERIALS: STAINLESS STEEL

O/A SIZE: Ø 444.5mm x 40mm (Ø 17.5" x 1.575")

QUANTITY: ONE

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JOB TITLE	12" TRIAXIAL CELL
UNIVERSITY OF BATH	SCH. OF ARCH. & B.ENG
SCALE	1:2
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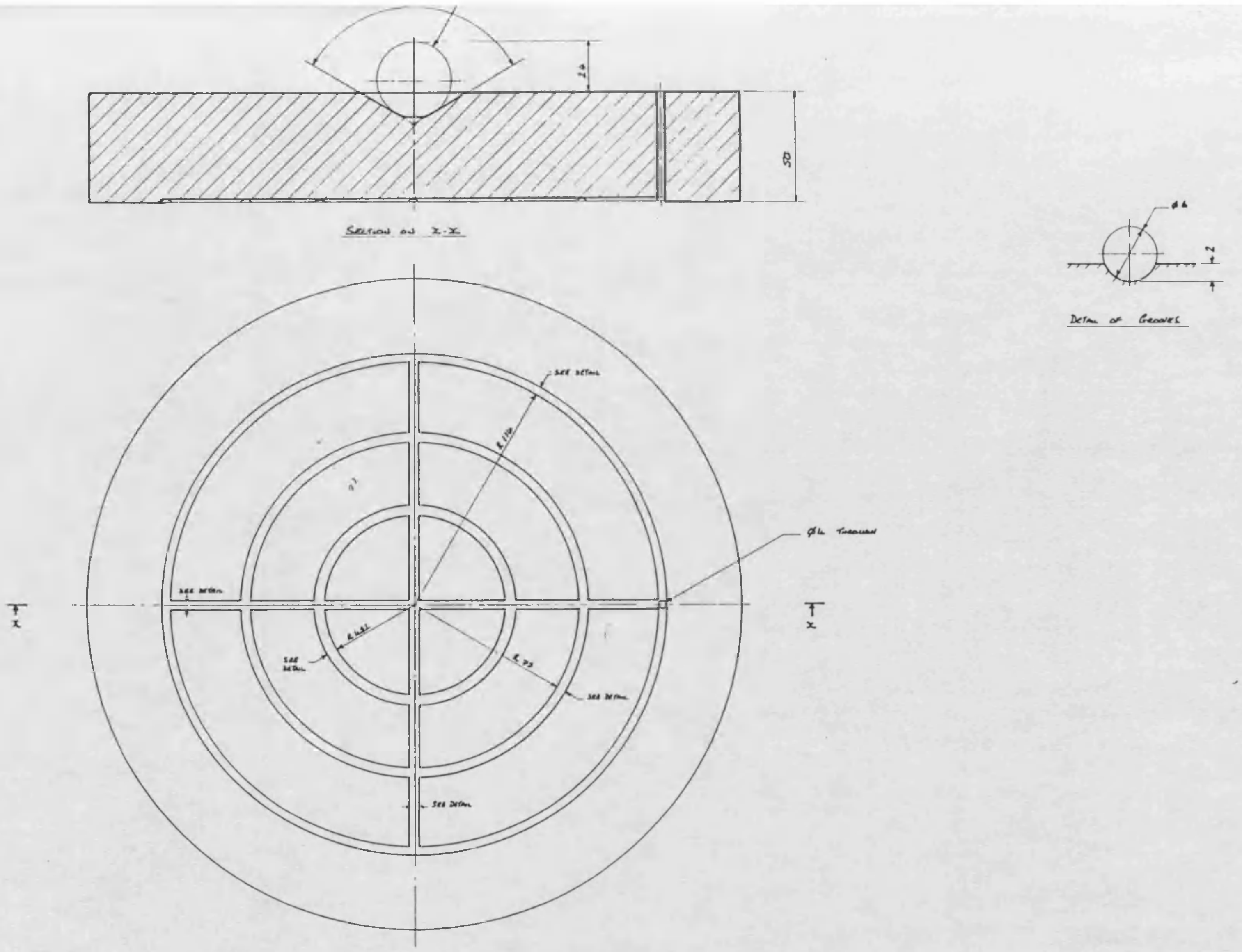

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O/A SIZE	: Ø 304.8mm × 50mm (Ø 12" × 1.969")
QUANTITY	: ONE

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JOB TITLE: 12" TRIAXIAL CELL		
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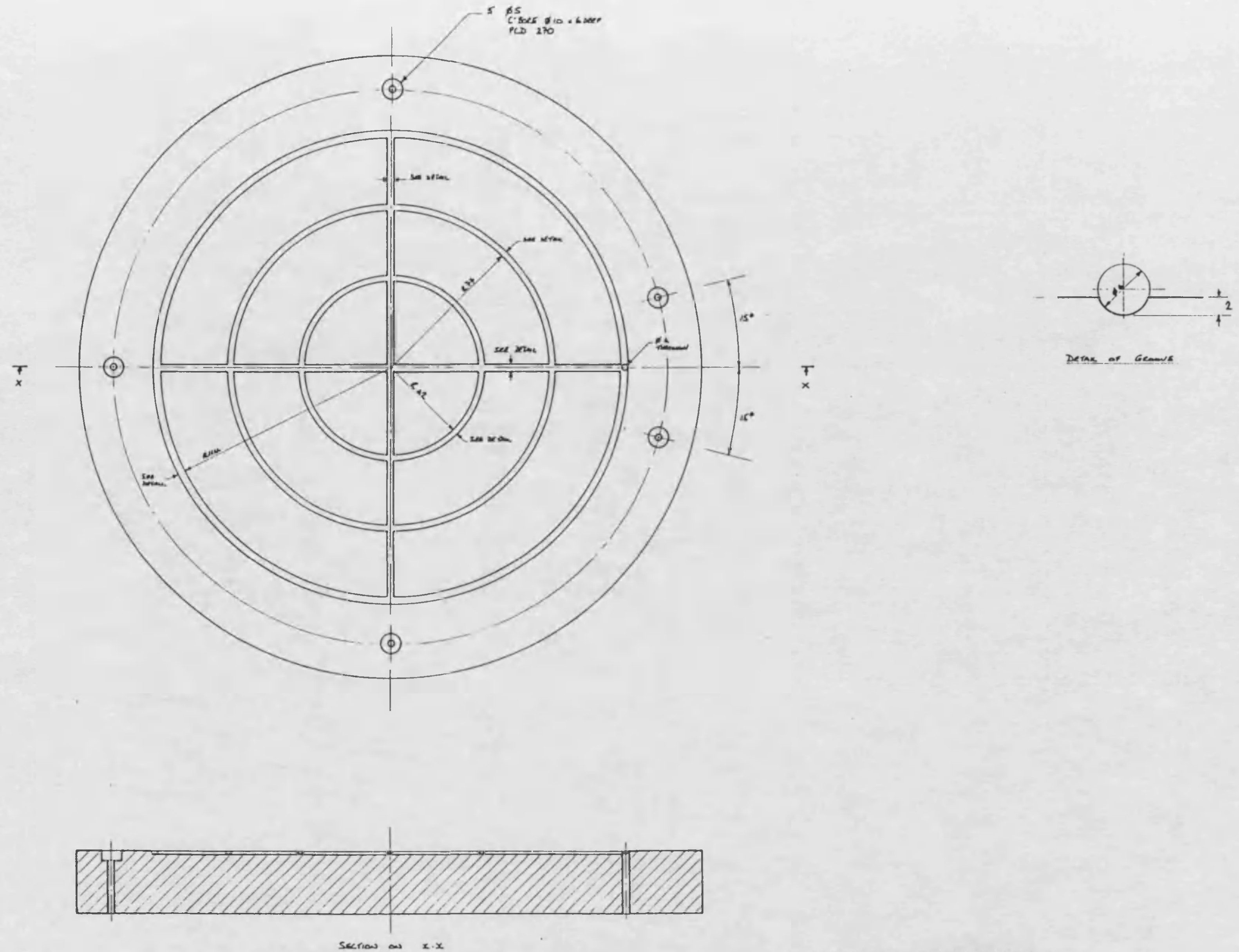

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O/A SIZE : Ø 304.8 × 30mm (Ø 12" × 1.18")

QUANTITY : ONE

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JOB TITLE: 12" TRIAXIAL CELL		
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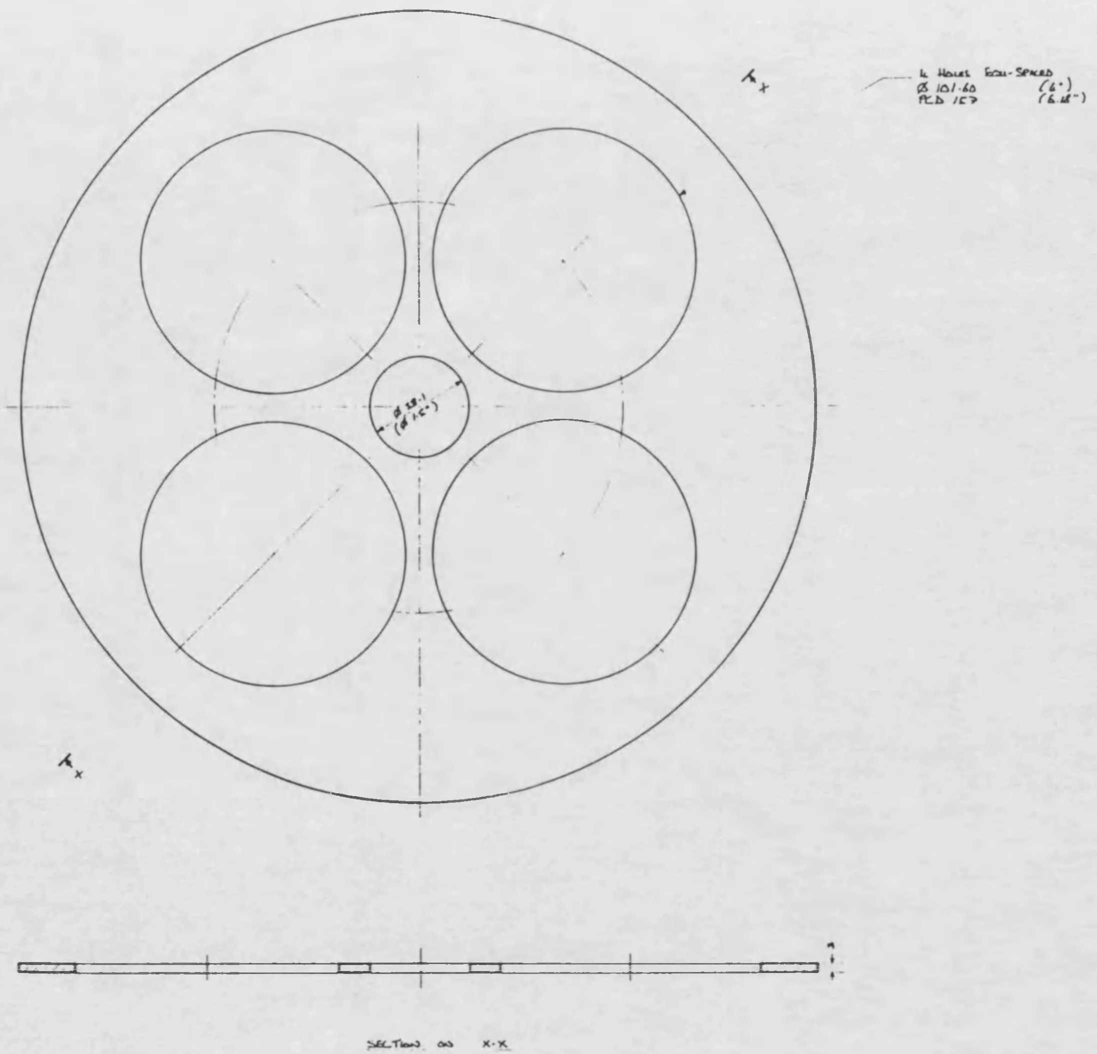

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MATERIAL TYPE: ALUMINIUM
O/A SIZE : Ø 306.8mm x 3mm (Ø 12" x 0.118")

QUANTITY : TWO

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JOB TITLE: 12" TRIAXIAL CELL	
UNIVERSITY OF BATH	SCH. OF ARCH. & B. ENG
SCALE 1:1	
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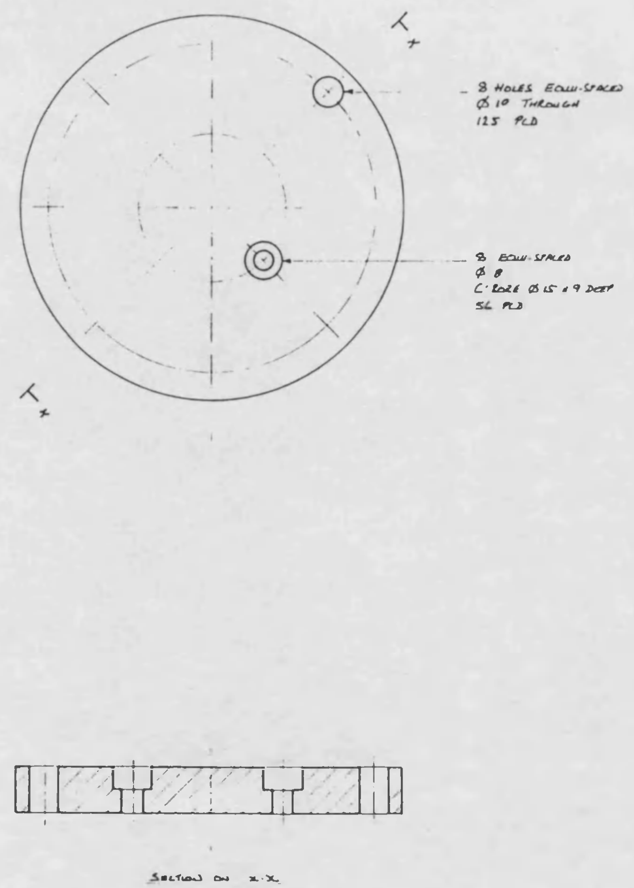

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MATERIAL : MILD STEEL

O/A SIZE : Ø 167mm x 18mm

QUANTITY : ONE

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JOB TITLE : 12" TRIAXIAL CELL	
UNIVERSITY OF BATH SCH. OF ARCH. + E ENG.	
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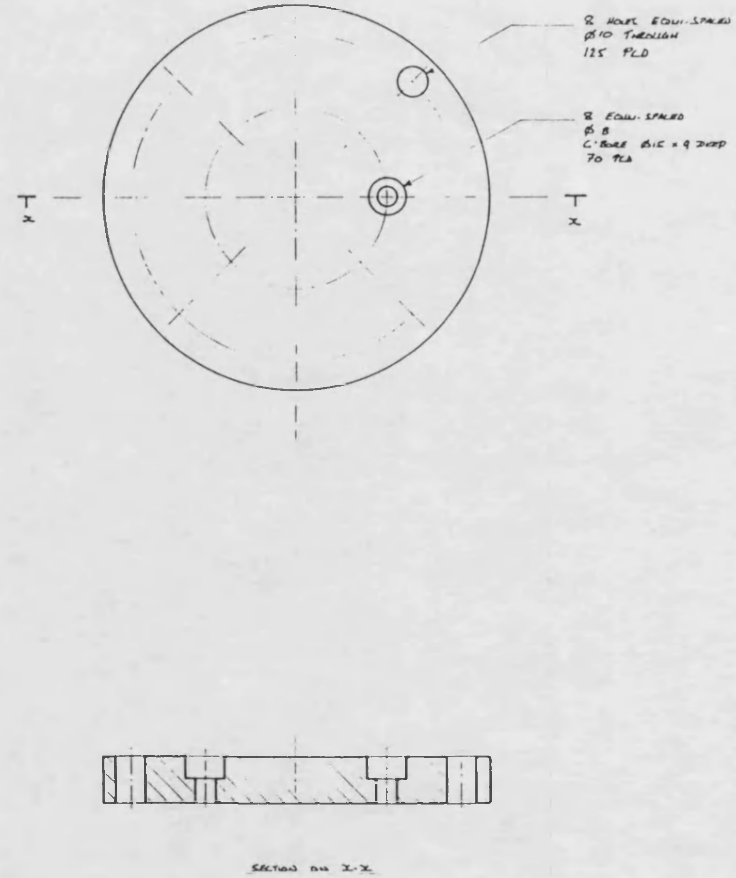

ALL DIMENSIONS IN mm UNLESS OTHERWISE STATED

MATERIAL : MILD STEEL

O/A SIZE : Ø 167 x 18mm

QUANTITY : ONE

DO NOT SCALE OFF DRAWING

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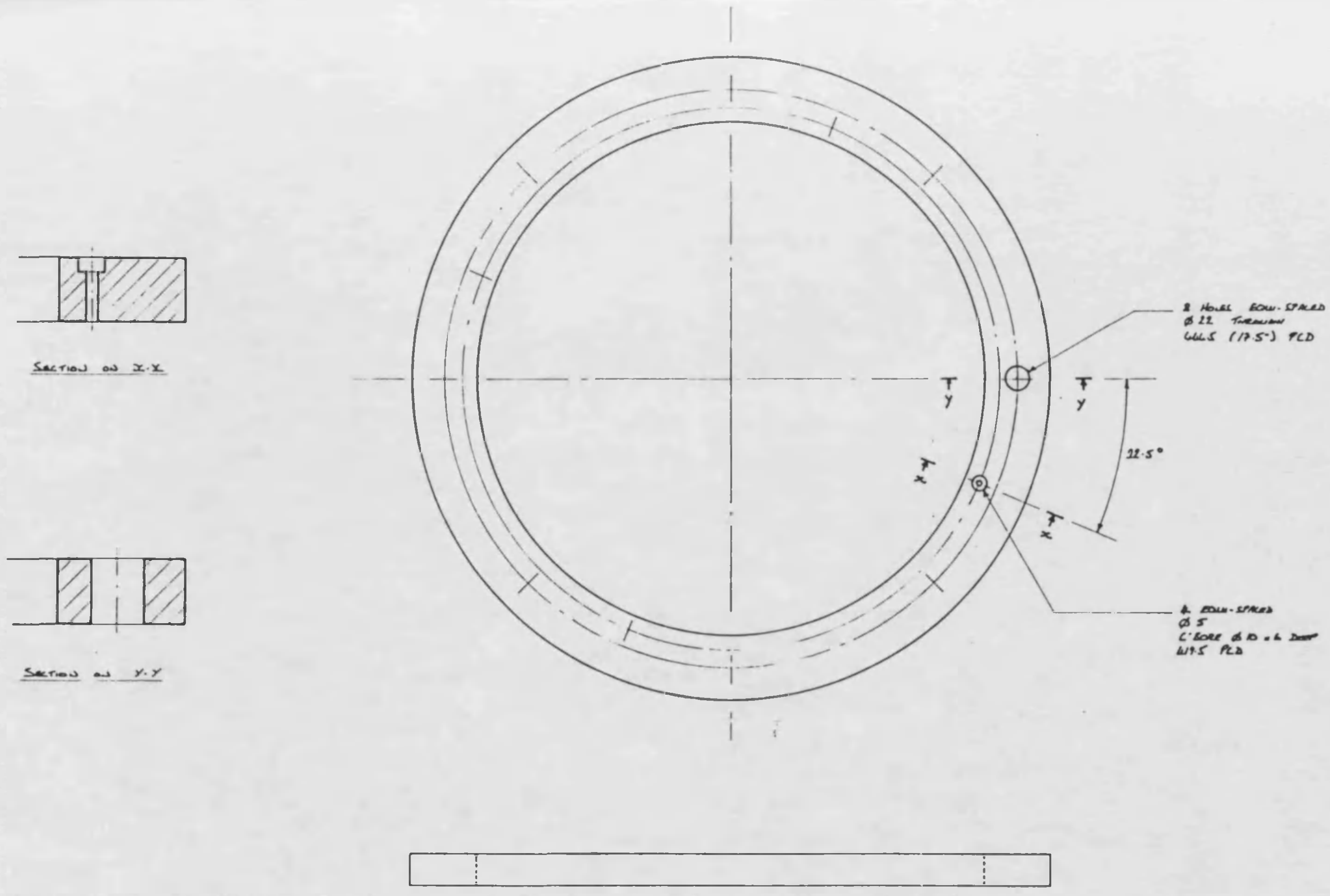
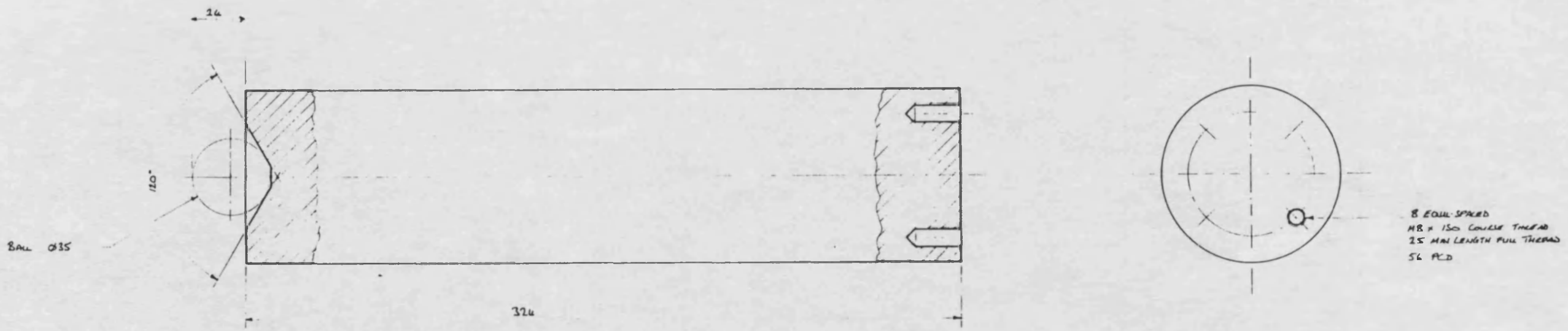


ALL DIMENSIONS IN mm UNLESS OTHERWISE STATED

MATERIAL : MILD STEEL	DRWG. TITLE : BOLT RINGS
O/A SIZE : OUTER DIA. 694.5mm (INNER DIA 594.5mm) x 20mm	JOB TITLE : 12" TRIAXIAL CELL
QUANTITY : TWO	UNIVERSITY OF BATH SCH OF ARCH & B ENG
	SCALE 1:2
DO NOT SCALE OFF DRAWING	DATE 8/7/88 — DRWG. BY J.L.R. — DRWG. No 10/15



ALL DIMENSIONS IN MM UNLESS OTHERWISE STATED

MATERIAL: STAINLESS STEEL
O/A SIZE: Ø 80mm x 324mm

QUANTITY: ONE

DO NOT SCALE THIS DRAWING

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JOB TITLE ?? TRIAXIAL CELL		
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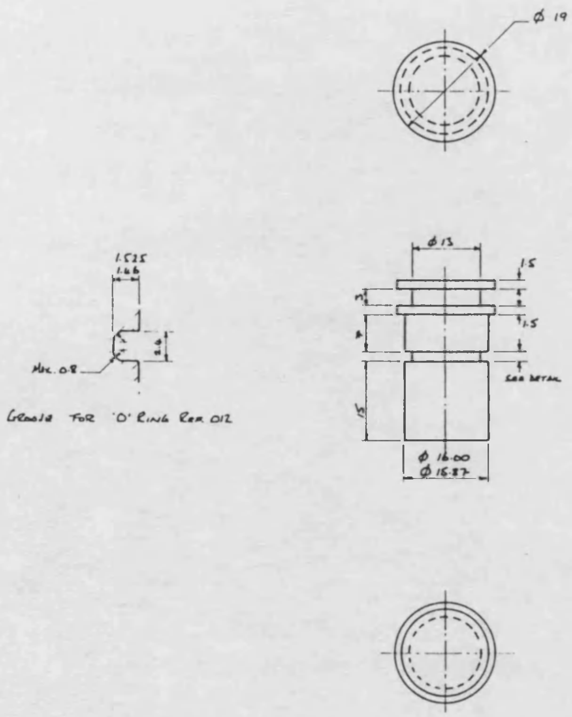

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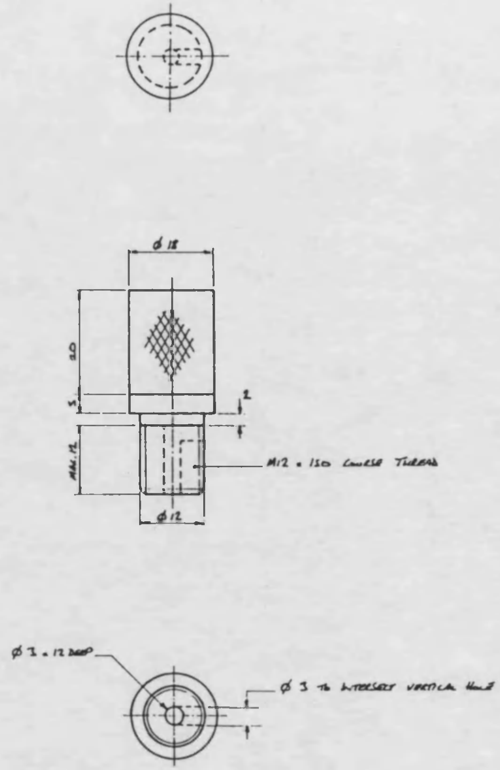


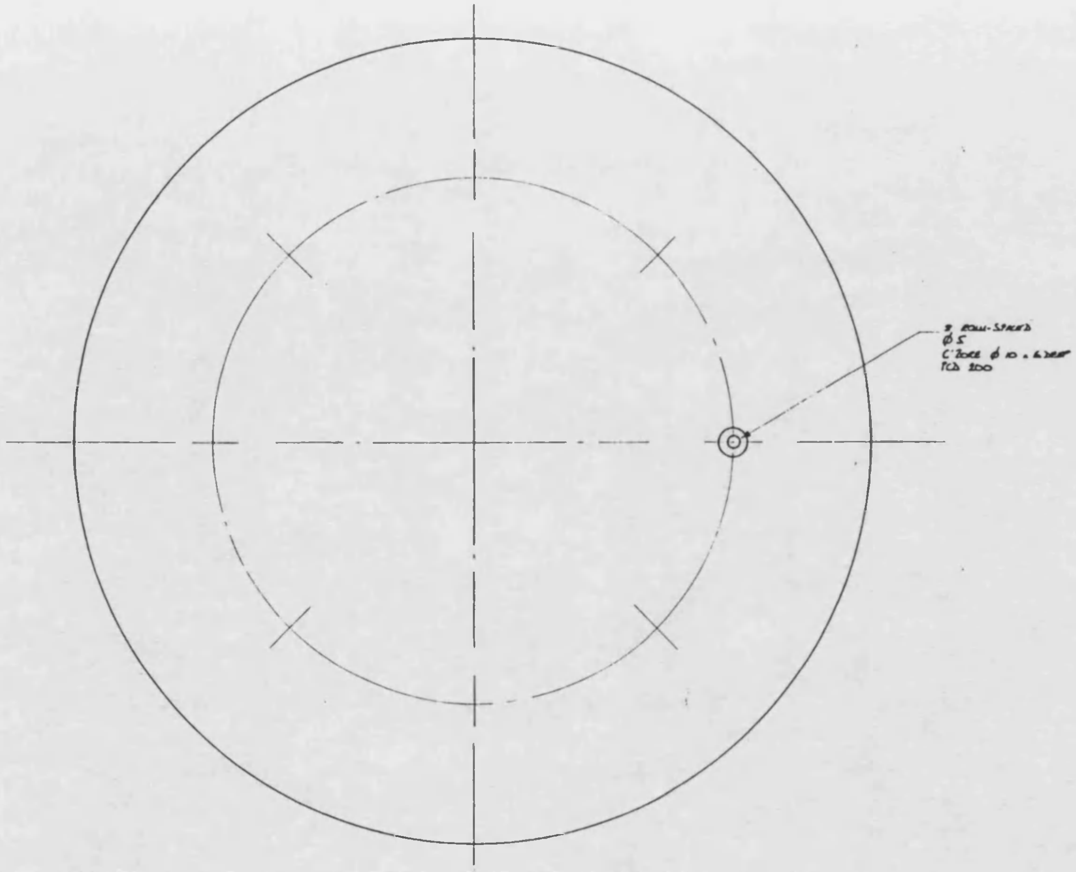
BLEED VALVE

ALL DIMENSIONS IN mm UNLESS OTHERWISE STATED

MATERIAL TYPE : STAINLESS STEEL
O/A SIZE : PLUG Ø 19mm × 32mm ; BLEED VALVE Ø 18mm × 37mm
QUANTITY : PLUG 9 (NINE) OFF ; BLEED VALVE ONE

DO NOT SCALE OFF DRAWING

DRWG TITLE: BLEED VALVE & PLUG DETAILS		
JOB TITLE: 1½" TRIAXIAL CELL		
UNIVERSITY OF BATH SCH. OF ARCH. & B. ENG.		
SCALE 2:1		
DATE 15/7/85	DRWN. BY S. G. R.	DRWG. No. 12/15



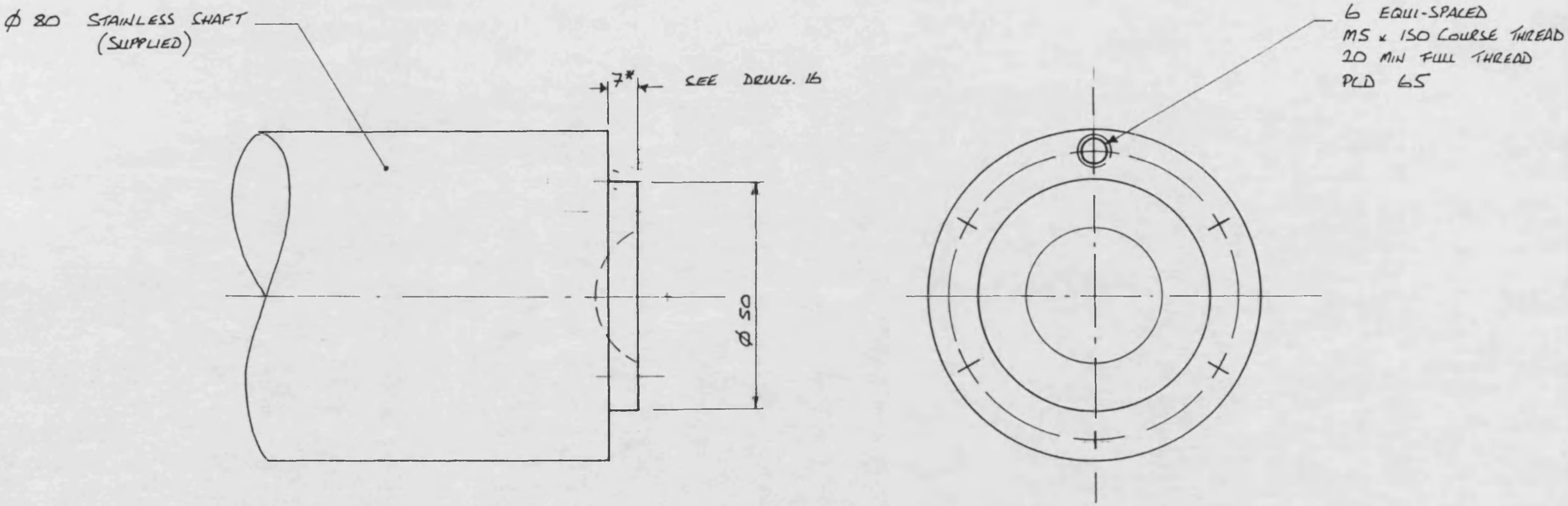
ALL DIMENSIONS IN mm UNLESS OTHERWISE STATED

MATERIAL TYPE : MILD STEEL
O/A SIZE : Ø 304.8mm x 50mm (Ø12" x 1.968")

QUANTITY : ONE

DO NOT SCALE OFF DRAWING

DRWG. TITLE : SUPPORT PLATE	
JOB TITLE : 12" TRIAXIAL CELL	
UNIVERSITY OF BATH SCH. OF ARCH & B. ENG.	
SCALE 1:1	
DATE 13/7/88	DRWG. BY S. G. R.
DRWG. No. 13/15	

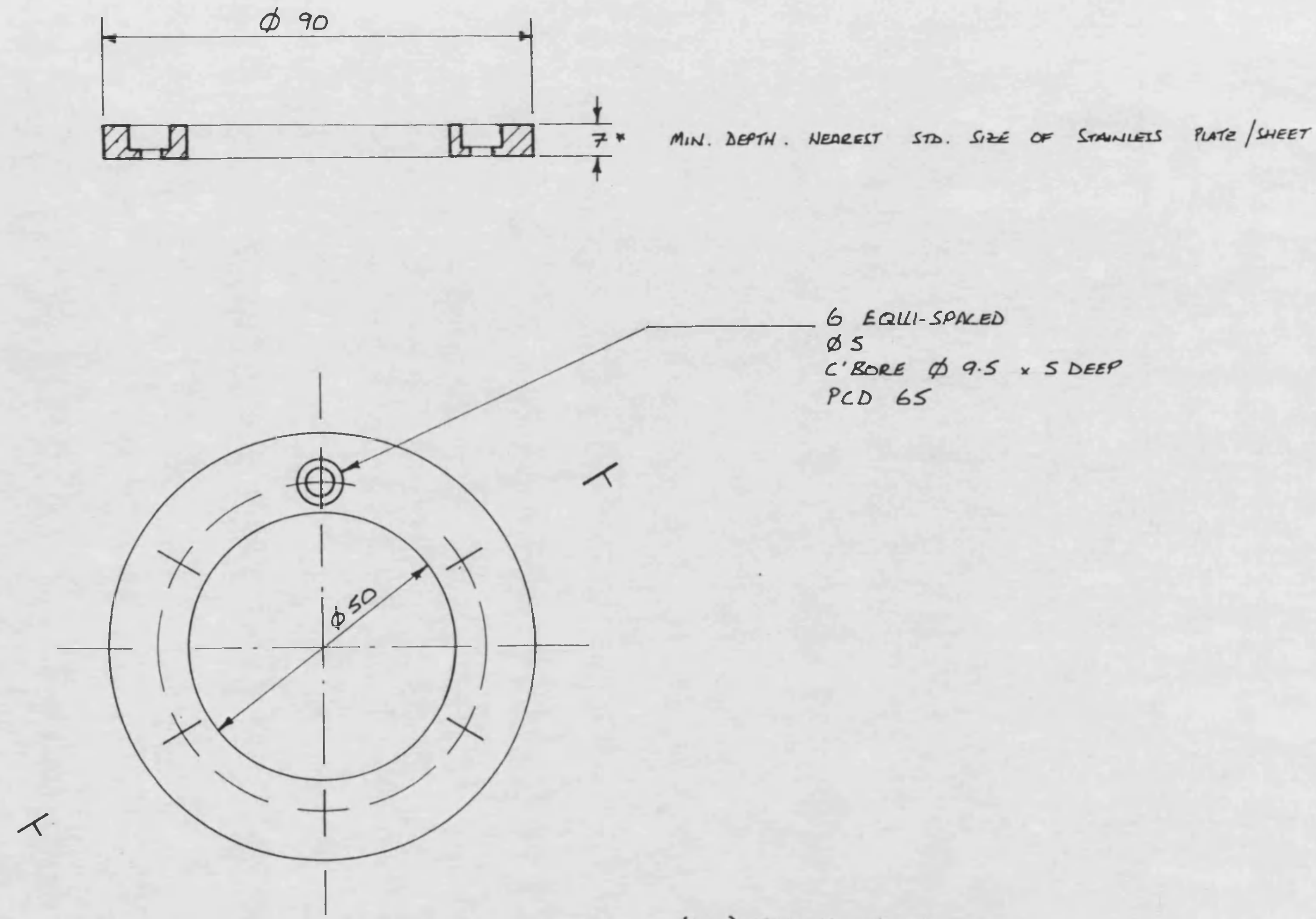


ALL DIMENSIONS IN mm

DO NOT SCALE OFF DRAWING

MATERIAL:	STAINLESS STEEL
O/A SIZE:	MODIFICATION TO EXISTING SHAFT AS SHOWN
NO. OFF:	

JOB. TITLE: 12" TRIAXIAL CELL		
DWG. TITLE: LOADING RAM MODIFICATION		
DWN. BY: S.G.R	DATE: 19/1/89	DWG. NO. 17



ALL DIMENSIONS IN MM

MATERIAL: STAINLESS STEEL	DO NOT SCALE OFF DRAWING	JOB. TITLE 12" TRIAXIAL CELL		
O/A SIZE: Ø 90 x 7*		DWG. TITLE RAM PRESSURE PLATE		
No. OFF: ONE		DRW. BY. S.G.R.	DATE 19/1/89	DWG. NO. 16

APPENDIX 2 Modification to air/water pressure system

Details of Stepper Motor modification to air/water pressure system.

As mentioned in section 5.2 there was a need to provide a means of applying cyclic loading to the existing 100mm triaxial cells. A selection of these utilised the constant air/water pressure system explained in section 5.2. By adapting this syatem to include remote control of the regulator valve, the air pressure could be varied throughout the test.

The approach selected was to use a stepper motor mechanically linked to the regulator and controlled by a computer. Because a stepper motor moves in distinct uniform 'steps' its position is defined simply by counting the number of steps from a reference point. This removes the need to use additional position indicators and to incorporate them in a closed feedback loop with the associated timing and interfacing problems. Thus, as long as the stepper motor can be remotely controlled to a suitable tolerance a simpler open control system may be adopted.

A common example of a stepper moter utilising an open control system is in computer printers, whereby the printer head is moved by a linear stepper motor without any position indicators. The printer head is precisely positioned by accurate control of the number of pulses sent to the stepper motor.

There are possible errors in the system, but for any given stepper motor these are not cumulative. They are not a function of the number of pulses sent, but are a feature of the mechanical design of the internal elements of the motor. It is not intended to give a description of stepper motor design here. The reader is referred to reference 33 in the bibliography if this is of interest.

The nature of the task considered here was to utilise a rotary stepper motor, connected via a mechanical fixing to an air regulator valve, in order to provide a variable air pressure. Two basic requirements were;

1. Accurate calibration of the air regulator, such that the pressure change due to any rotation throughout its range is defined.

2. Control system to send the appropriate number of pulses to the stepper motor in response to setup data.

It must be noted that an open control loop control system within this application is only satisfactory for load control. In order to control the system so that a defined rate of displacement is applied, a position sensor to monitor the movement due to any pressure change would be required. This would need to be fed back within the control loop to determine the next signal to the stepper motor, thus forming a closed feedback system. The use of a computer controlled system maintained the flexibility, if required, to monitor remote sensors and compare expected response to actual measurements. To incorporate these measurements into the feedback loop would be possible if phasing and timing considerations were dealt with.

Standard stepper motor control cards are on the market, but were unavailable to this project. An advantage of designing and manufacturing a specific control card is that it can be taylor ed to the specific application. The control card had to perform a number of functions;

1. Receive a signal from the controlling computer. It was decided to use a standard ASC II serial signal for the command 'string', specifying the direction and amount of movement required from the stepper motor.

2. Convert the analogue command signal to digital form to enable processing.

3. Processing of the command signal.

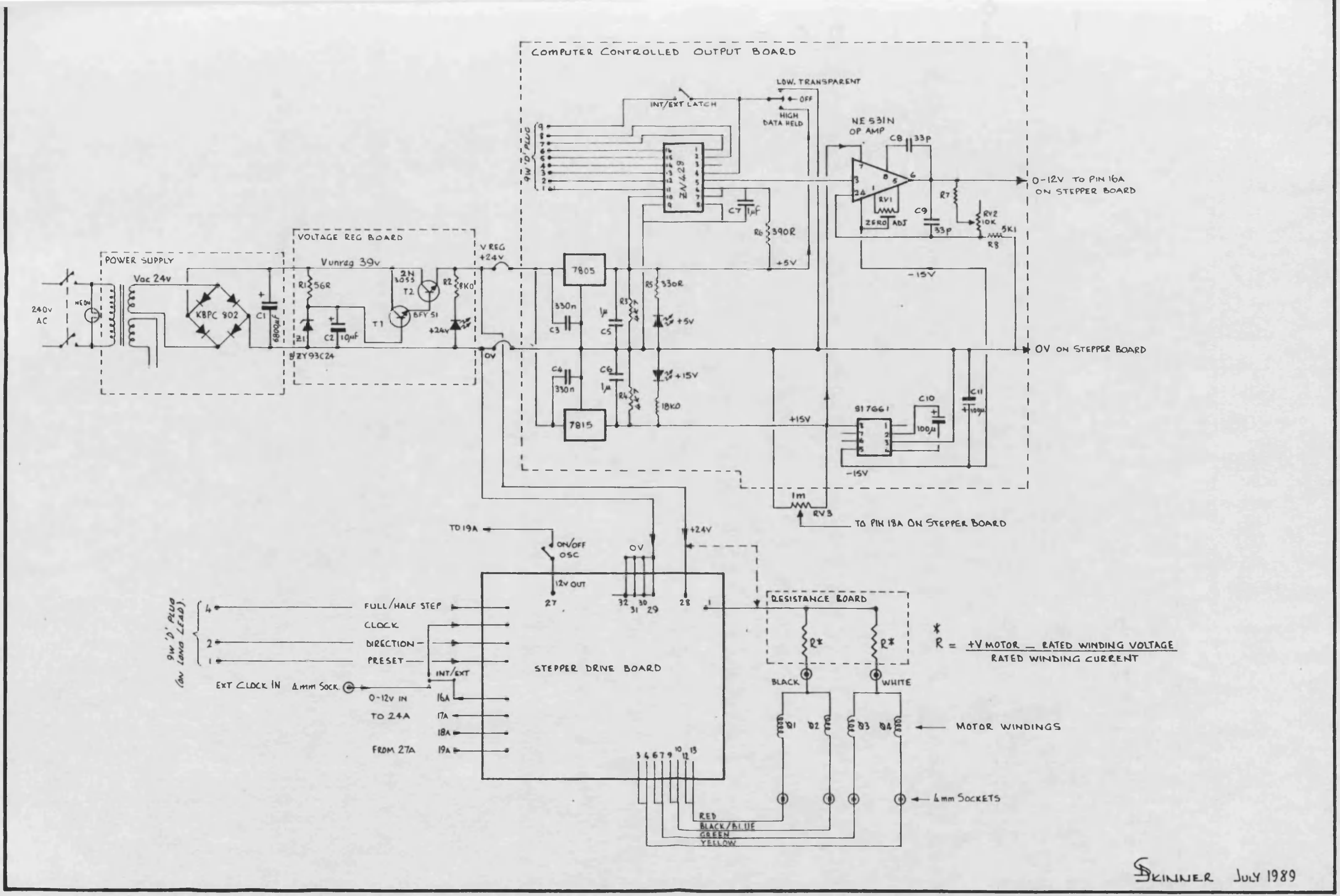
4. Stepper motor pulse generator.

The developed wiring details are included with reference material at the end of this section.

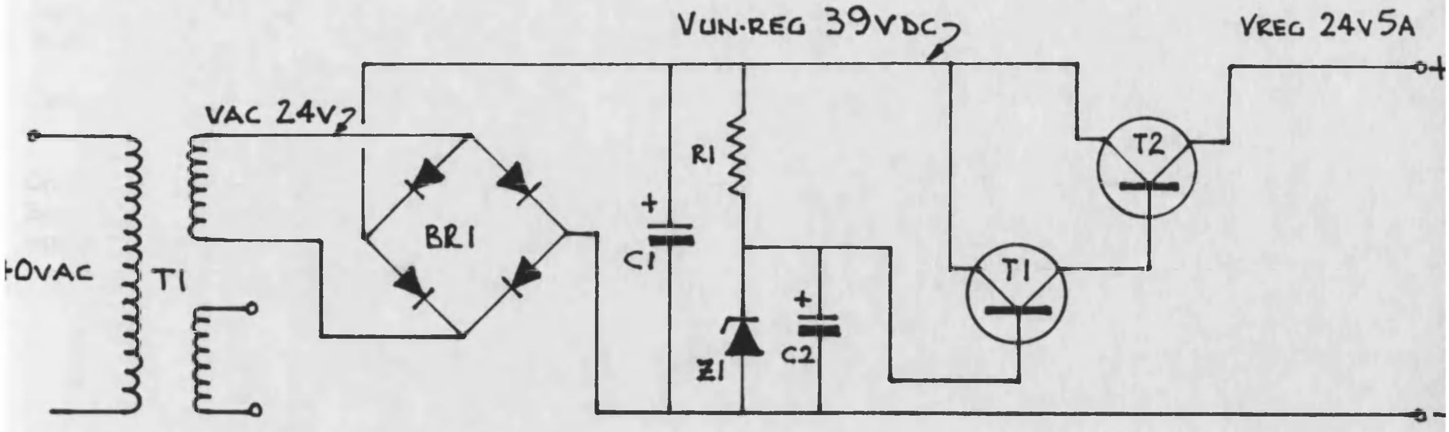
A BBC micro computer was chosen as the controller, due to the ability to directly access the I/O ports. Following development of the system, any processor capable of sending the required ASC II 'string' command via an RS 232 interface could be used.

Whilst the control system operated satisfactorily, the air/water pressurising system could not react to the changes at the air regulator. Pulsing occurred within the pipework, and compression in the air system modified the pressure at the air/water interface. To overcome these problems the pressure side could be converted to a full hydraulic system. There might still be a need to utilse a fully closed feedback control loop which negates the principal advantage of using a stepper motor. Closed feedback systems are more appropriate to AC motors.

As stated in the main text, the commissioning of a new structures laboratory removed the need for further development.


COMPUTER CONTROLLED OUTPUT BOARD
LOW. TRANSPARENT
INT/EXT LATCH
OFF
HIGH DATA HELD
NE 531N OP AMP
ZN428
9W 'D' PLUG
C8 33P
C7 1μF
R6 390R
RV1
ZERO ADJ
C9 33P
R7
RV2 10K
5K1 R8
0-12V TO PIN 16A ON STEPPER BOARD
VOLTAGE REG BOARD
POWER SUPPLY
Vunreg 39v
Vac 24v
240v AC
NEON
KBPC 802
C1 6800μF
R1 56R
2N 3055
T2
R2 8K0
T1
BFY 51
+24v
Z1
C2 10μF
BZY93C24
V REG +24v
0V
7805
7815
330n
C3
C4 330n
C5 1μ
C6 1μ
R3
R4
R5 330R
+5V
+15V
18K0
-15V
0V ON STEPPER BOARD
+15V
SI 7661
C10 100μ
C11 100μ
1m
RV3
TO PIN 18A ON STEPPER BOARD
TO 19A
ON/OFF OSC
12V OUT
+24V
STEPPER DRIVE BOARD
FULL/HALF STEP
CLOCK
DIRECTION
PRESET
INT/EXT
9W 'D' PLUG (ON LONG LEAD)
EXT CLOCK IN 4mm SOCK
0-12v IN
TO 24A
FROM 27A
16A
17A
18A
19A
RESISTANCE BOARD
R*
BLACK
WHITE
Ø1 Ø2 Ø3 Ø4
MOTOR WINDINGS
4mm SOCKETS
RED
BLACK/BLUE
GREEN
YELLOW
* R = +V MOTOR — RATED WINDING VOLTAGE / RATED WINDING CURRENT
SKINNER JULY 1989

POWER SUPPLY FOR STEPPER DRIVE



C1 = 6800 µF 40V

C2 = 10 Fµ 63v

R1 = 56R 7w

Z1 = ZENER 24V 6A

T1 = BFY 51

T2 = 2N3055E

BR1 = BRIDGE RECTIFIER 200V 8A

T1 = TRANSFORMER 200VA 0-24v 0-24V

D SKINNER.

4-Phase Unipolar Stepper Motor Drive Board 332–098

Technical specification:

Size	standard Euro card 168 x 100 x 15
Mating edge connector	standard 32-way DIN 41612 socket e.g. RS 471–503 or 467–453
Supply (board and motor)	15-30V d.c. +10% max. unregulated smoothed
Current consumption:	
a) board only	60mA
b) motor windings	dependent on motor used-up to 2A/phase max.
On-board auxiliary output	12V d.c. 50mA max. regulated
Switching logic control inputs	Level '0' 0V, Level '1' 12V } CMOS and open collector T.T.L. compatible
a) full/half step	Level '1' full step Level '0' half step
b) direction	
c) clock	1Hz-25kHz, 10µs min. pulse width negative edge triggered
d) preset	Active Level '0' sets motor drive states to Q1, & Q3 OFF, Q2 & Q4 ON (full step mode) Q1, Q2 & Q3 OFF, Q4 ON (Half step mode) - see fig. 1. Automatic preset at switch-on

Board Connections

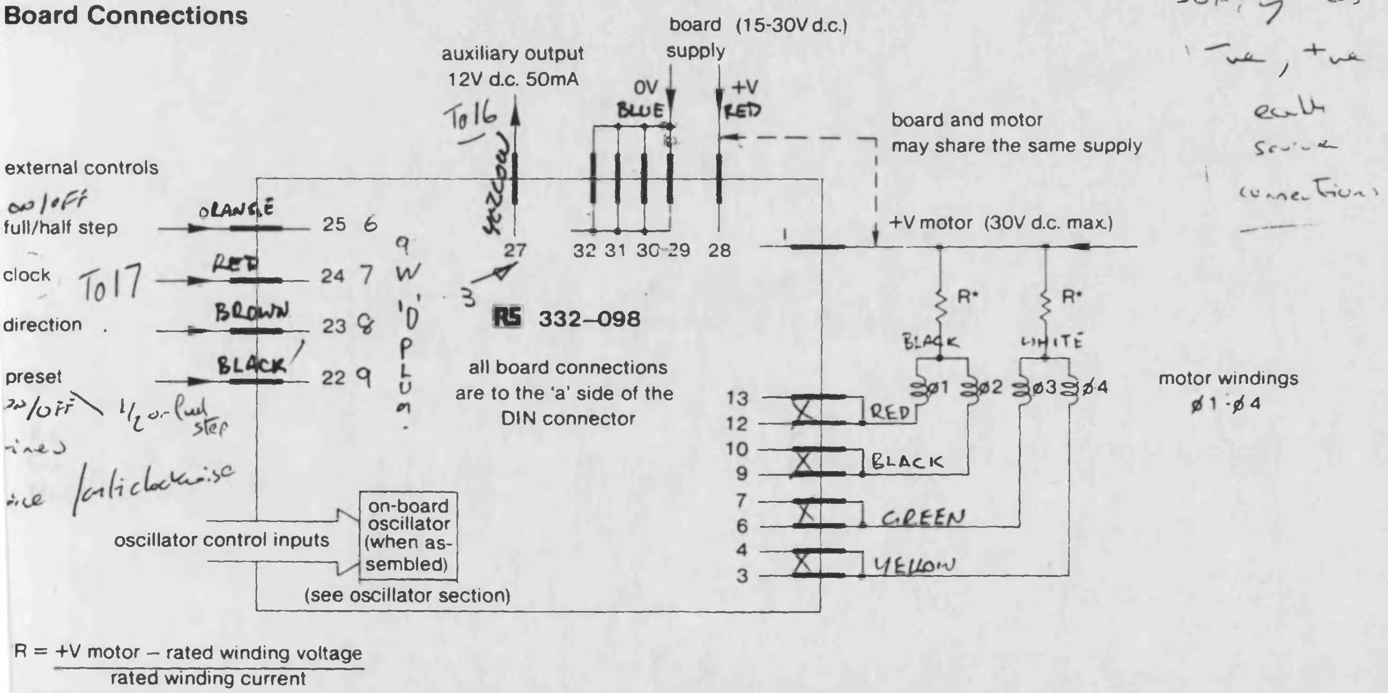


Fig. 1

ax. power dissipated through R = (rated motor current)^2 x R. If the power dissipation is high it is advisable to arrive at the required alue of R by using a network of series or parallel resistors. (The use of higher wattage resistors and heat sinks may be required).

ax. current consumption (motor & board) = 2 x (current per phase) +60mA. Thus ensure power supply cables used are ufficiently rated.

kternal control signals e.g. full/half step, direction etc. as well as the oscillator (if ted) stop/run signal can be applied to the circuit in any of the methods of fig. 2.

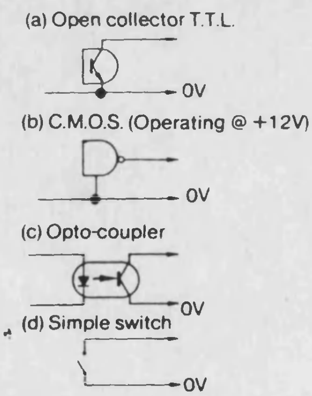
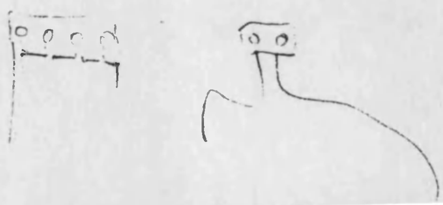


Fig. 2



Connection to RS stepper motors

When the windings of the RS Stepper Motors are assigned (Ø1 - Ø4) as shown in Fig. 3, they can be connected to the board according to Fig. 1.

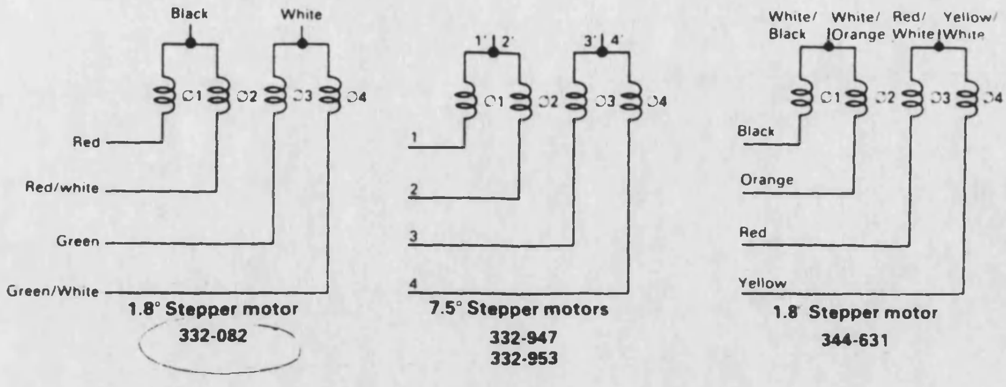


Fig. 3

If the supply voltage is set to 24V d.c. then R values for use with the RS motors are given in table 1 below:

motor	rated current (A)	rated winding votage (V)	R (Ω)	power dissipation through R (W)
332–947	0.1	12	120	1.2
332–953	0.24	12	47	3
332–082	1	5	19	19
344–631	1.7	3	12.3	36

Table 1

For other design details and motors performance refer to RS data sheet 5550 on stepper motors.

On-board oscillator assembly

If external clock source is not available, an on-board oscillator can be assembled simply by soldering into place the required RS Components listed below.
Note: the oscillator clock output must be externally wired to the clock, input-pin 24a).

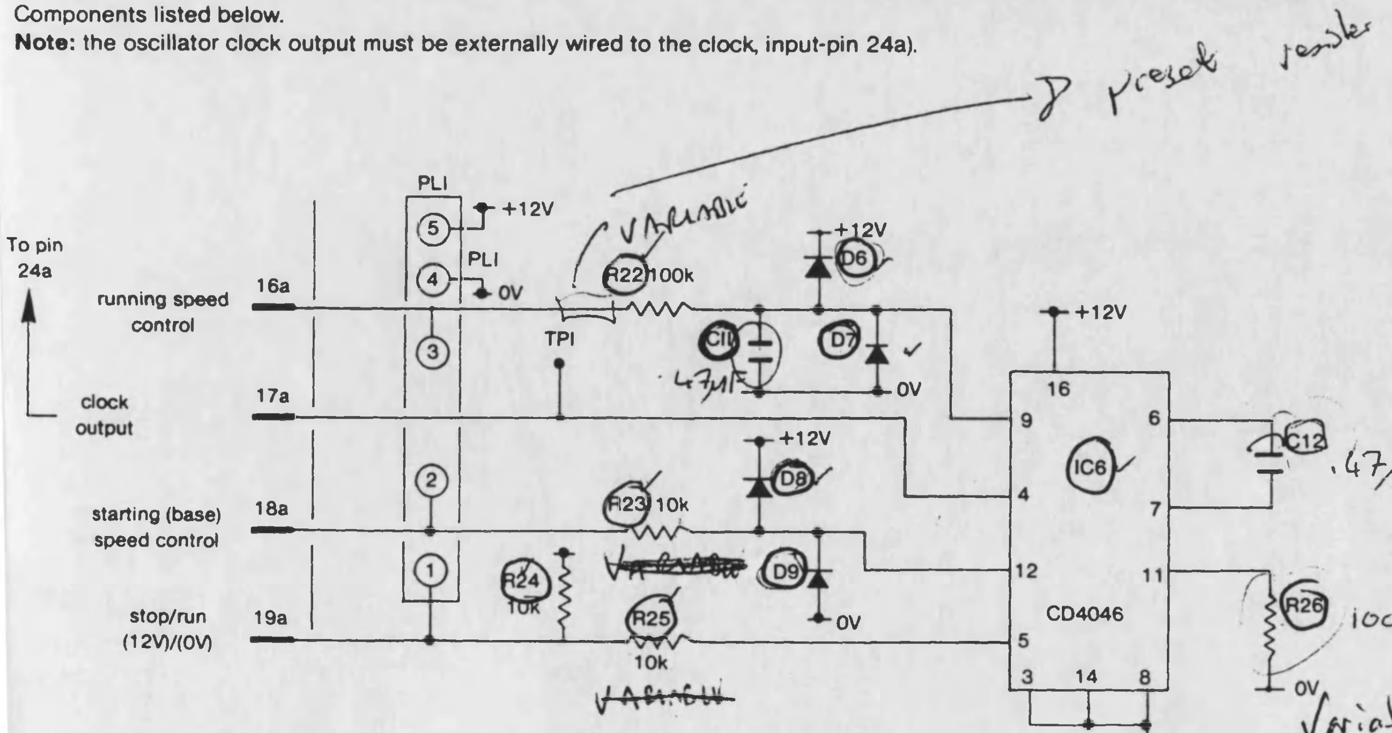


Fig. 4

R22	100KΩ resistor	RS 131–491	1 off	10 @
R23, 24, 25	10KΩ resistor	RS 131–378	3 off	10 @
D6, 7, 8, 9	signal diode	RS 271–606	4 off	10
IC6	CMOS I.C.	RS 306–645	1 off	1
R26, C11 & C12	(value depends on application)		1 off each	

If oscillator remote controls are required (e.g. front panel controls) then plug PLI (5-way RS inter-p.c.b. 467–576) can be added together with mating cable shell RS 467–627 and crimp terminals RS 467–598.

C11, C12 126 051 £2.60
R26 - 1002Ω

Starting (base) and running speed control

The on-board oscillator can be arranged to start at a fixed frequency (thus a fixed motor speed) and then ramp up to a final value (the running motor speed). This facility is available to start the motor within its pull-in performance region and then accelerate the motor through so that it can operate within the pull-out mode. On switch-off the motor decelerates automatically.

Three parameters need to be determined for any application:

a. The starting speed: this should be below the pull-in speed for the motor (with any additional load).
b. The running (final) speed: this should be within the pull-out capability of the motor (with any additional load).
c. The acceleration and deceleration rate between starting and running speeds: this is limited by the motor capability to accelerate through its own (plus any load) inertia.

Oscillator controls (external)

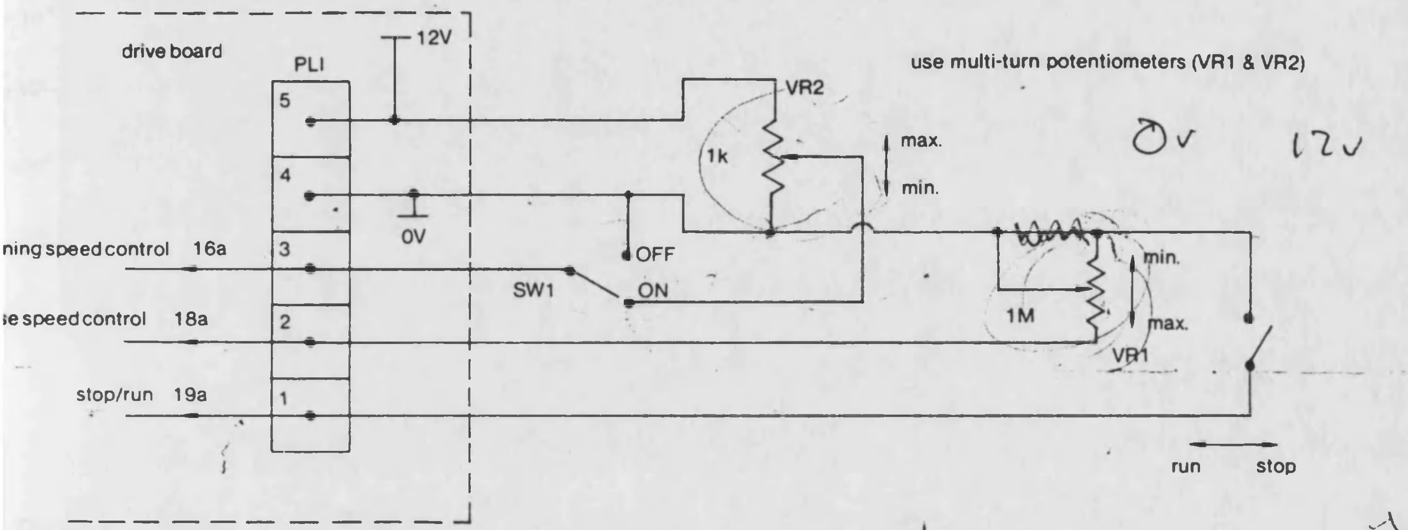


Fig. 5

Ω ohms

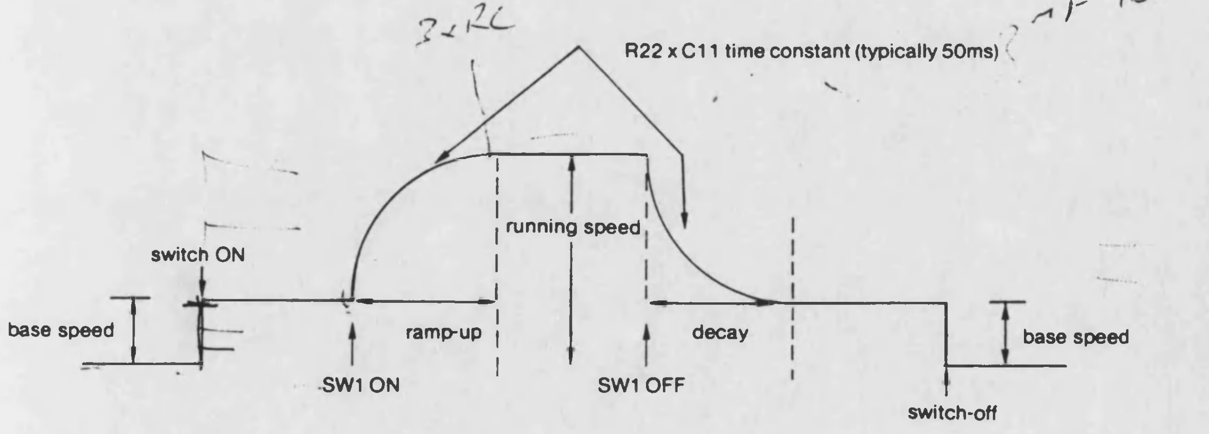


Fig. 6 Motor speed-ramping characteristic

Note: Oscillator frequency corresponds directly to motor speed in steps/s or half steps/s depending on motor drive mode.

For A 1.8° stepper motor
speed in revs/min = $\frac{60}{200}$ x speed in steps/s

or $\frac{60}{400}$ x speed in half steps/s

For A 7.5° stepper motor
speed in revs/min = $\frac{60}{48}$ x speed in steps/s

or $\frac{60}{96}$ x speed in half steps/s

Oscillator frequency setting

Recommended component values

VR1	0 – 1MΩ
VR2	1K Ω
R26	10K Ω – 1MΩ
C12	greater than 100pf

Determine the base frequency and maximum running frequency. Using Fig. 7 and the base frequency value choose a value for C12 and VR1. Calculate the ratio max. running frequency/base frequency to determine the ratio of $\frac{\text{VR1} + \text{R23 (fixed at 10k } \Omega)}{\text{R26}}$

and thus using Fig. 8 establish the required value for R26.

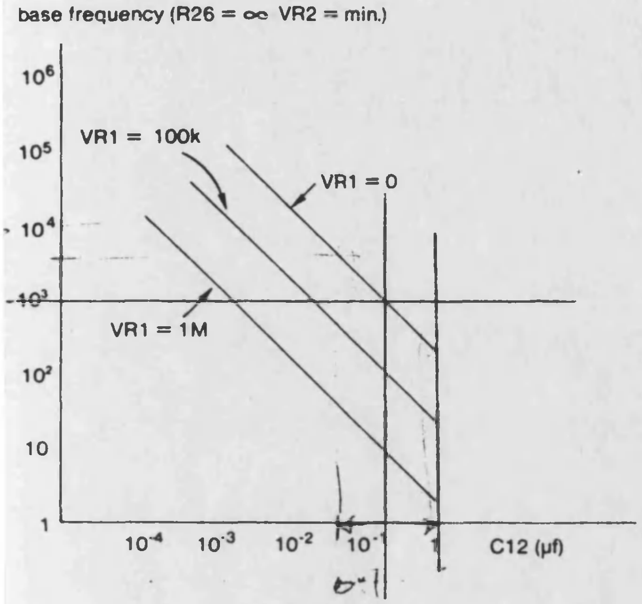


Fig. 7

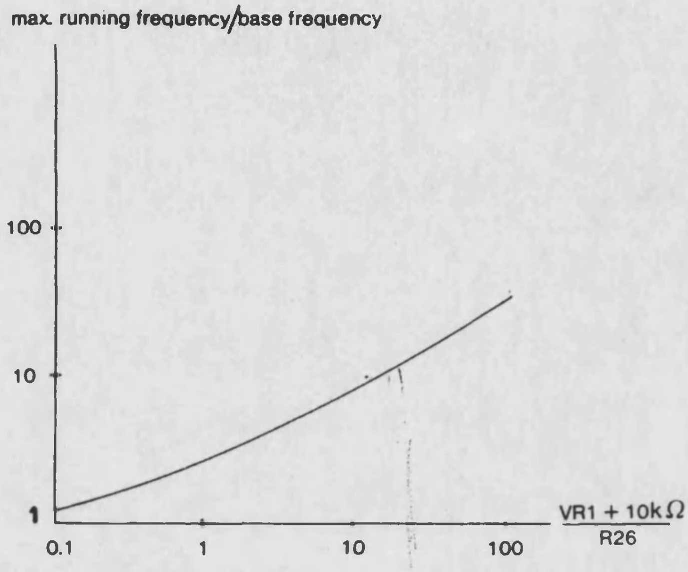


Fig. 8

Once all component values are established and assembled the oscillator frequency range is as shown in Fig. 9. If SW1 is OFF the oscillator runs at base frequency. When SW1 is ON the oscillator builds up (at a rate depending on R22 x C11 time constant) to a frequency determined by VR2 setting.

Pull

≈ 1000 – 2000 steps/sec

$0 \cdot 5 \times 10^{-6}$ sec

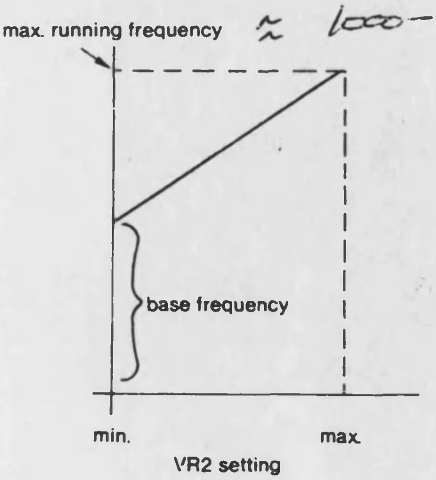


Fig. 9

? pull in rate for type 23 stepper motor

R. S. COMPONENTS LIMITED
13-17 Epworth Street
London EC2P 2HA
Telephone 01-253 1222

DATA SHEET

8 Bit D to A/A to D Converter I.C.

DESCRIPTION

The ZN425E is an 8 bit dual mode analogue to digital/digital to analogue converter. It contains an 8 bit D to A converter using an advance design of R-2R ladder network and an array of precision bipolar switches plus an 8 bit binary counter and a 2.5 volt precision voltage reference all on a single monolithic chip.

The special design of ladder network results in full 8 bit accuracy using normal diffused resistors.

The use of the on-chip reference voltage is pin optional to retain flexibility. An external fixed or varying reference may therefore be substituted.

By including on the chip an 8 bit binary counter, analogue to digital conversion can be obtained simply by adding an external comparator (531) and clock inhibit gating (7400).

By simply clocking the counter the ZN425E can be used as a self-contained precision staircase ramp generator.

A logic input select switch is incorporated which determines whether the precision switches accept the outputs from the binary counter or external digital inputs depending upon whether the control signal is respectively high or low.

FEATURES

- Dual mode, Digital to Analogue/Analogue to Digital
- On chip precision voltage reference
- Includes 8 bit binary counter
- Will function as precision staircase ramp generator
- TTL and CMOS compatible
- Direct voltage output
- 16 pin D.I.L. encapsulation

PIN CONNECTIONS (TOP VIEW)

Function	Pin	Pin	Function
Ground	1	16	V_{REF} Output
Logic Select	2	15	V_{REF} Input
Counter Reset	3	14	Analogue Output
Clock	4	13	Bit 1 (M.S.B.)
Bit 8	5	12	Bit 2
Bit 7	6	11	Bit 3
Bit 6	7	10	Bit 4
$+V_{CC}$	8	9	Bit 5

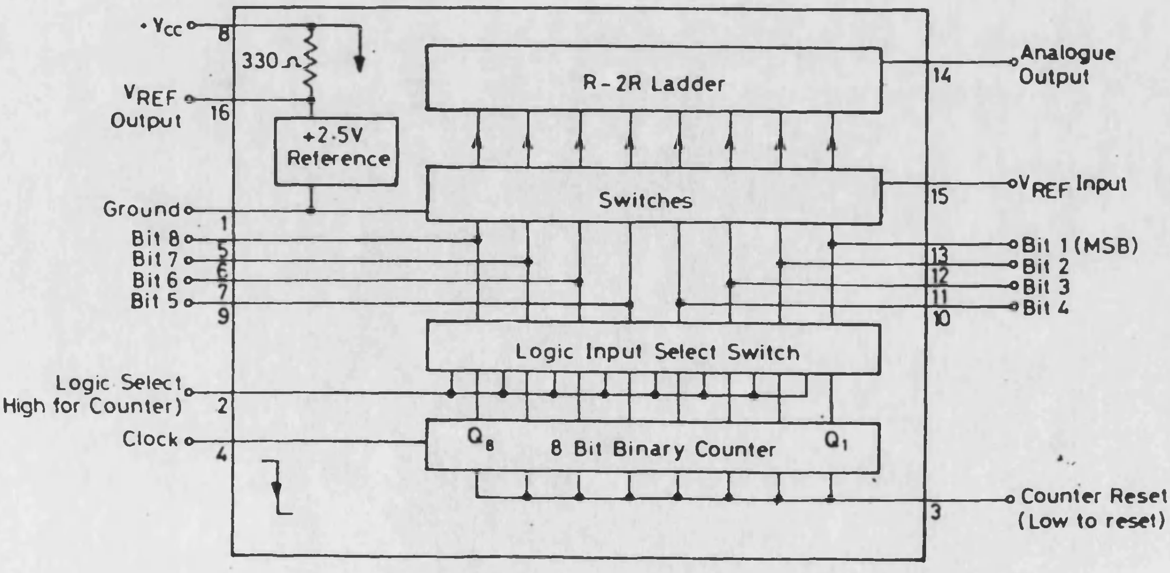


Fig. 1 Block Diagram

3SOLUTE MAXIMUM RATINGS

Supply voltage V_{CC}	+7.0 volts
Max. voltage, logic and V_{REF} inputs	+5.5 volts
Operating temperature range	0 to +70 C
Storage temperature range	-55 to +125 C

HARACTERISTICS (at T_{amb} = 25 C and V_{cc} = +5 volts unless otherwise specified).

Parameter	Symbol	Min.	Typ.	Max.	Units	Conditions
Supply voltage	V_{CC}	4·5	—	5·5	volts	
Supply current	I_s	—	30	40	mA	
High level input voltage	V_{IH}	2·0	—	—	volts	See notes 1 and 2
Low level input voltage	V_{IL}	—	—	0·7	volts	
High level input current	I_{IH}	—	—	10	µA	V_{CC} = max., V_I = 2·4V
		—	—	100	µA	V_{CC} = max., V_I = 5·5V
.ow level input current	I_{IL}	—	—	–0·68	mA	V_{CC} = max., V_I = 0·3V
ligh level output current	I_{OH}	—	—	–40	µA	
.ow level output current	I_{OL}	—	—	1·6	mA	
ligh level output voltage	V_{OH}	2·4	—	—	volts	V_{CC} = min., Q = 1, I_{load} = –40µA
ow level output voltage	V_{OL}	—	—	0·4	volts	V_{CC} = min., Q = 0, I_{load} = 1·6 mA

3it D to A Converter

Parameter	Symbol	Min.	Typ.	Max.	Units	Conditions
inearity error		—	—	±0·5	L.S.B.	
ettling time		—	1·0	—	µs	1 L.S.B. step
ettling time to 0·5 L.S.B.		—	2·0	—	µs	All bits ON to OFF or OFF to ON
ffset voltage	V_{OS}	—	3·0	—	mV	All bits OFF
os Temperature coefficient		—	5	—	µV/°C	
S.R. Temperature coefficient		—	3	—	ppm/°C	Ext. V_{REF} = 2·5V
nearity Error Temperature coefficient		—	7·5	—	ppm/°C	Relative to F.S.R.
ıalogue output resistance	R_o	—	10	—	k ohm	
ternal reference voltage		0	—	3·0	volts	

rnal voltage reference

Parameter	Symbol	Min.	Typ.	Max.	Units	Conditions
ıtput voltage	V_{REF}	—	2·55	—	volts	I = 7·5 mA (internal)
ope resistance	R_s	—	2	—	ohms	I = 7·5 mA (internal)
EF Temperature coefficient		—	40	—	ppm/°C	I = 7·5 mA (internal)

es:

1. The Logic Select pin (2) must be held low when the bit pins (5, 6, 7, 9, 10, 11, 12 and 13) are driven externally.
2. To obtain counter outputs on bit pins the Logic Select pin (2) should be taken to $+V_{CC}$ via a 1 kΩ resistor.
3. The internal reference requires a 0.22 µF stabilising capacitor between pins 1 and 16.

APPLICATIONS

8 bit D to A Converter

The ZN425E gives an analogue voltage output directly from pin 14 therefore the usual current to voltage converting amplifier is not required. The output voltage drift, due to the temperature coefficient of the Analogue Output Resistance R will be less than 0.004% per °C (or 1 L.S.B./100°C) if R is chosen to be ≥ 650kΩ

In order to remove the offset voltage and to calibrate the converter a buffer amplifier is necessary. Fig 2 shows a typical scheme using the internal reference voltage. To minimise temperature drift in this and similar applications the source resistance to the inverting input of the operational amplifier should be approximately 6kΩ. The calibration procedure is as follows:

i. Set all bits to OFF (low) and adjust R_2 until V_{out} = 0.000V.

ii. Set all bits to ON (high) and adjust R_1 until V_{out} = Nominal full scale reading –1 L.S.B.

iii. Repeat i. and ii.

e.g. Set F.S.R. to +3.840 volts –1 L.S.B.

= 3.825 volts

$$(1\ \text{L.S.B.} = \frac{3.84}{256} = 15.0\ \text{millivolts.})$$

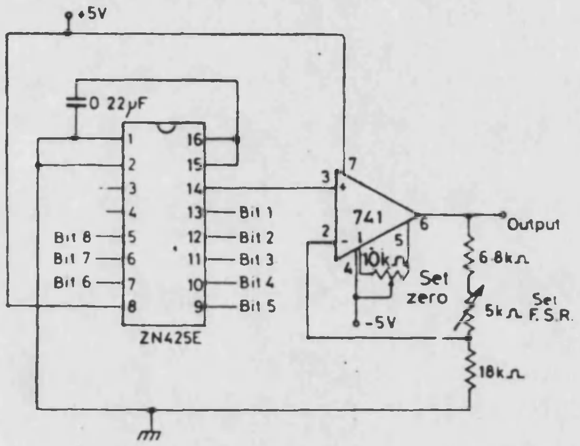


Fig 2. 8 Bit Digital to Analogue Converter

8 bit Analogue to Digital Converter

A counter type analogue to digital converter can be constructed by adding a voltage comparator as in Fig 3. On the negative edge of the CONVERT COMMAND Pulse the counter is set to zero and the STATUS output to logical 1. On the positive edge the counter starts to count up from zero. The analogue output ramps until it equals the analogue voltage applied to the other input of the comparator. At this point, any further clock pulses are inhibited and STATUS goes low to indicate that the output data is valid.

The conversion time depends upon the value of the analogue input and for full scale reading is given by the clock frequency divided into the maximum number of counts.

For example if F_{clock} = 256K

$$\text{conversion (for F.S.R.)} = \frac{2^8}{256{,}000}\ \text{seconds}$$

$$= 1\ \text{millisecond}$$

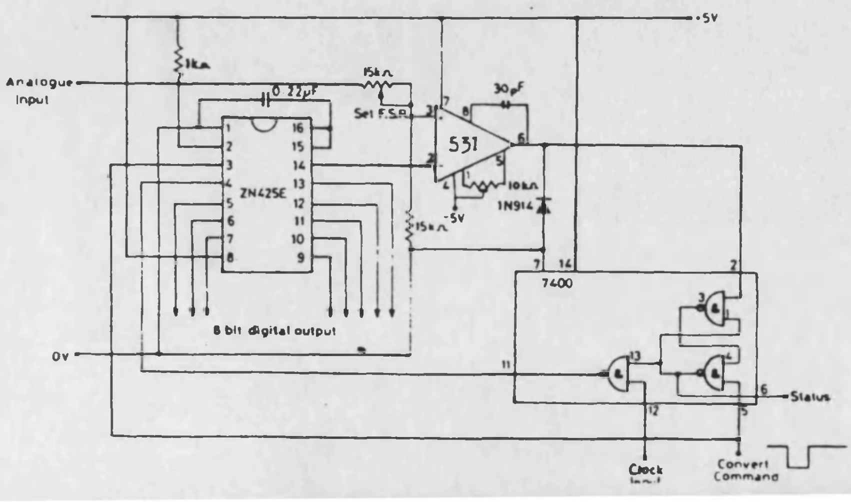


Fig 3. 8 Bit Analogue to Digital Converter

Precision Staircase Ramp Generator

The inclusion of an 8 bit binary counter on the chip gives the ZN425E a useful staircase ramp generator function. The circuit, Fig 4 uses the same buffer stage as the D to A converter. The calibration procedure is also the same. Holding pin 2 low will set all bits to ON and if RESET is taken low with pin 2 high all the bits are turned OFF. If the end voltages of the ramp are not required to be set accurately then the buffer stage could be omitted and the voltage ramp will appear directly at pin 14. (N.B. Resetting of the output may take place at any point of the waveform by taking pin 3 [reset] low.)

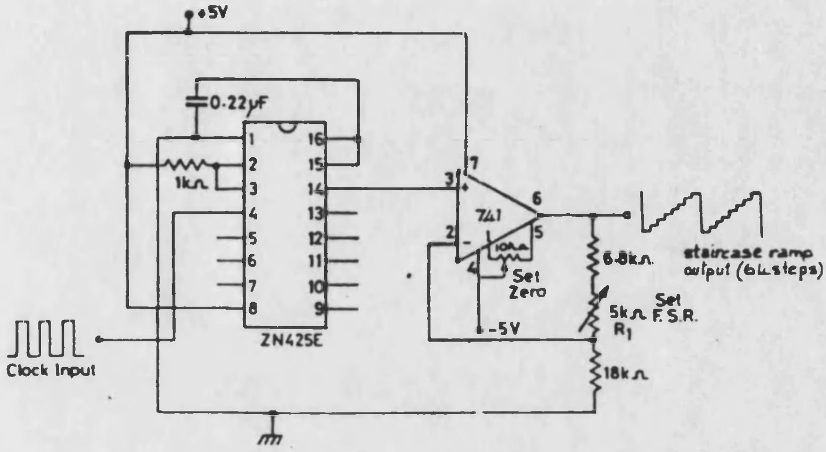


Fig 4. Precision Staircase Ramp Generator.

APPENDIX 3 Non contacting displacement transducer details

NON CONTACTING DISPLACEMENT TRANSDUCERS

These transducers utilise the inductive technique to measure the relative distance between a 'sender' unit and a 'target', and are unaffected by water. These systems allow a resolution as fine as 0.2 nanometers, although 0.12 to 0.25 micrometers is more common.

The inductive principle is as follows. An AC current flowing in a coil causes the field of one winding to add to the field of the next winding. The fields pulsate, in turn generating an AC electromagnetic field surrounding the coil. Placing the coil a nominal distance from a target induces a current flow (the 'eddy current') on the surface and within the target. The induced current produces a second magnetic field that opposes and thus reduces the intensity of the original field with resultant changes in the impedance of the exciting coil. These changes are analysed by signal conditioning electronics to give information about the target.

In the transducers considered here, produced by Kaman Measuring Systems, the sensing coil is a leg of a balanced wheatstone bridge network. As the target moves toward the coil, the current flow increases in the target and losses within the bridge network increase, and visa versa as the target moves away. The bridge network responds to these unbalanced conditions, and the output of the bridge is amplified, demodulated and presented as a linear analogue signal directly proportional to the targets position, which in turn can be displayed on a digital readout.

The measurement range of the system is a direct function of the surface diameter of the sensor. As the sensor diameter increases so does the measurement range, but, the resolution decreases. Thus, the selection of an appropriate sensor configuration is dependent on space considerations, and a compromise between range and resolution.

For the application of measuring the radial expansion/contraction of soil samples within the large triaxial cell during the cyclic testing, four sensors were considered a minimum requirement inorder to assess and average the sample movement. These would be arranged with two sensors placed diametrically opposite one another on the 1/3rd points of the sample. A four channel system with sensors with a measurement range of 15mm and a resolusion of 0.0015 mm was proposed. However as stated within the main text, cost constraints ruled out this option.

APPENDIX 4 Calibration Data for Strain Rings and Calibration Certificates for Proprietary Transducers

Calibration data for the Strain Rings.

Includes;

1. Stiffness test results.

2. XY plots of RESPONSE vs INDUCED DISPLACEMENT for each 1/2 bridge for each strain ring, utilising DIALOG software and screen dump.
3. Yt plot of RESPONSE vs TIME for each 1/2 bridge for each strain ring. Utilising DIALOG software and screen dump.
4. Calculation sheet for the conversion factors.

The raw numerical data is not presented as the graphical output represents the better format indicating the response in a more appropriate manner, as discussed in section 8.1 in the main text.

STRAIN RING STIFFNESS TEST RESULTS

These tests consisted of hanging small weights from the strain rings and measuring the resulting deformation. Measurements were recorded whilst the rings were being loaded and unloaded in order to ensure the response was similar for extension and contraction.

Weight [N]	Absolute Deformation reading on scale rule. [mm] Loading	Unloading
hanger only (50g)	405	404
+ 0.5	402	401
+ 0.5	399	399
+ 0.5	396	398
+ 0.5	396	

Weight [N]	Loading	Unloading
self weight		410
+ hanger (50g)	408	408
+ 0.5	406	406
+ 0.5	404	406
+ 0.5	402	402
+ 0.5	400	

Weight [N]	Loading	Unloading
self weight	410	410
+ hanger (50g)	409	408
+ 0.5	407	406/7
+ 0.5	405	404/5
+ 0.5	403	402
+ 0.5	400/1	

Average stiffness value = 2 mm/N, 0.5 N/mm

Strain Ring Conversion Factor Calculation Sheet

As mentioned in section 8.1, each 1/2 arrangement on each strain ring is identified by the Ring no. and the monitoring channel no.

Data taken from XY plots and numerical listings as appropriate.

RING No. 1

Channel no. 11

Induced Displacement [mm] = 4.98164

Response [ADU units] = 778

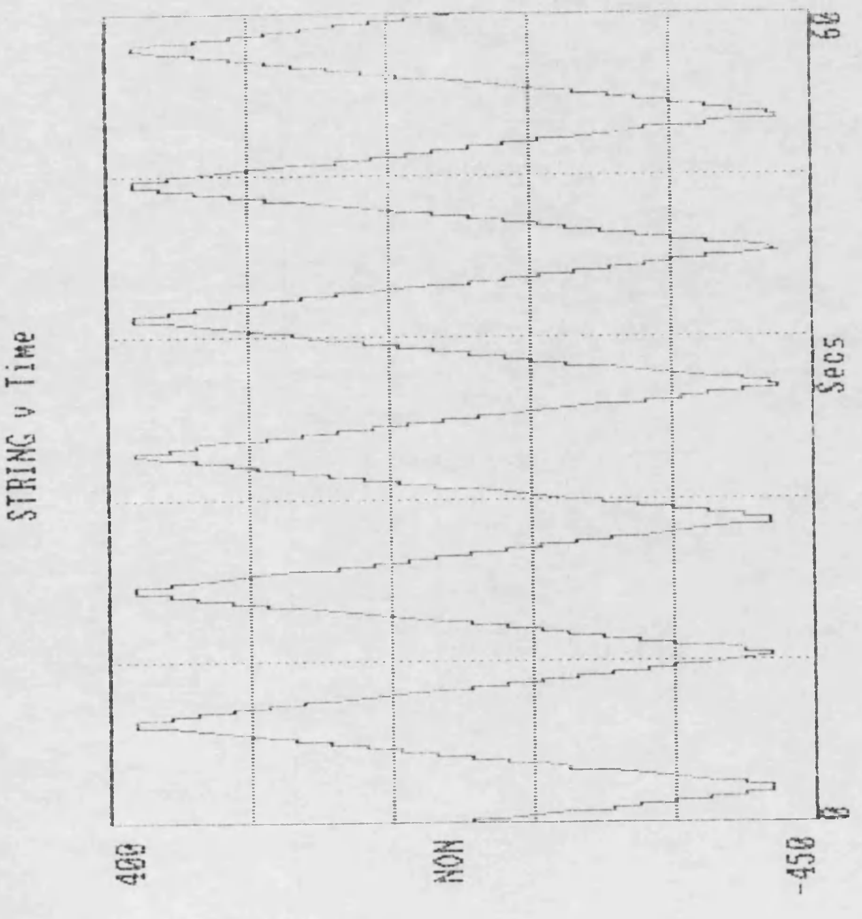
Conversion Factor = 6.403×10^{-3} mm/unit

Channel no. 15

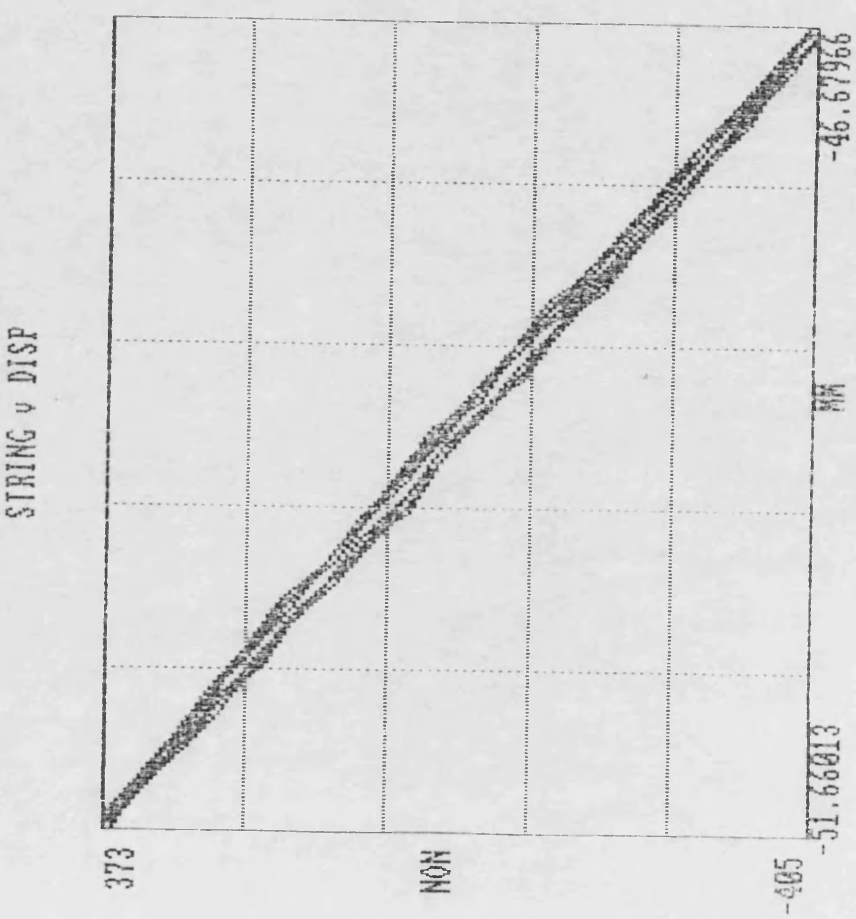
Induced Displacement [mm] = 4.98164

Response [ADU units] = 662

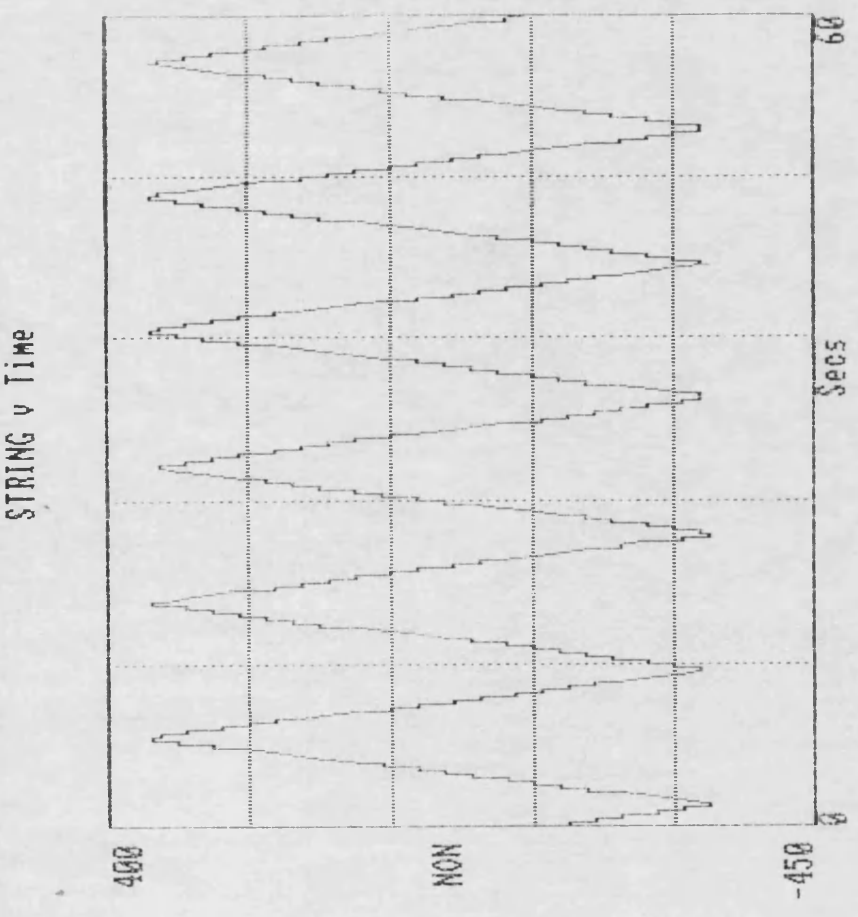
Conversion Factor = 7.525×10^{-3} mm/unit



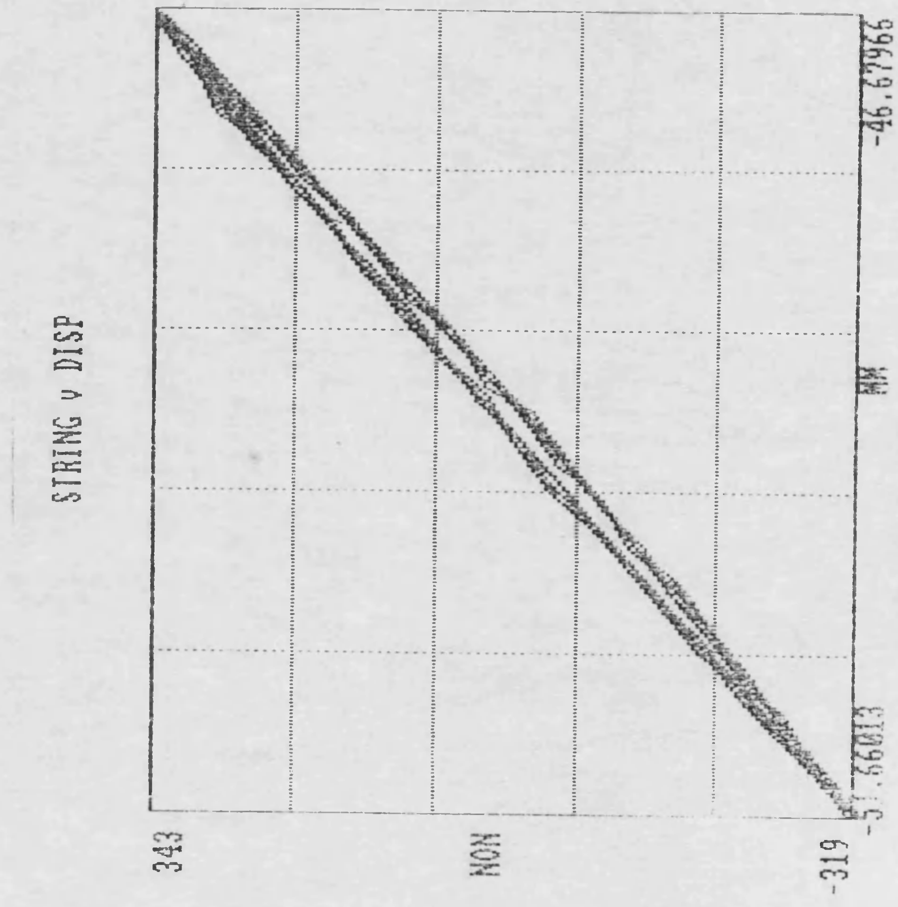
RING 1/11



RING 1/11



RING 1/15



RING 1/15

Strain Ring Conversion Factor Calculation Sheet

As mentioned in section 8.1, each 1/2 arrangement on each strain ring is identified by the Ring no. and the monitoring channel no.

Data taken from XY plots and numerical listings as appropriate.

RING No. 2

Channel no. 14

Induced Displacement [mm] = 4.98047

Response [ADU units] = 350

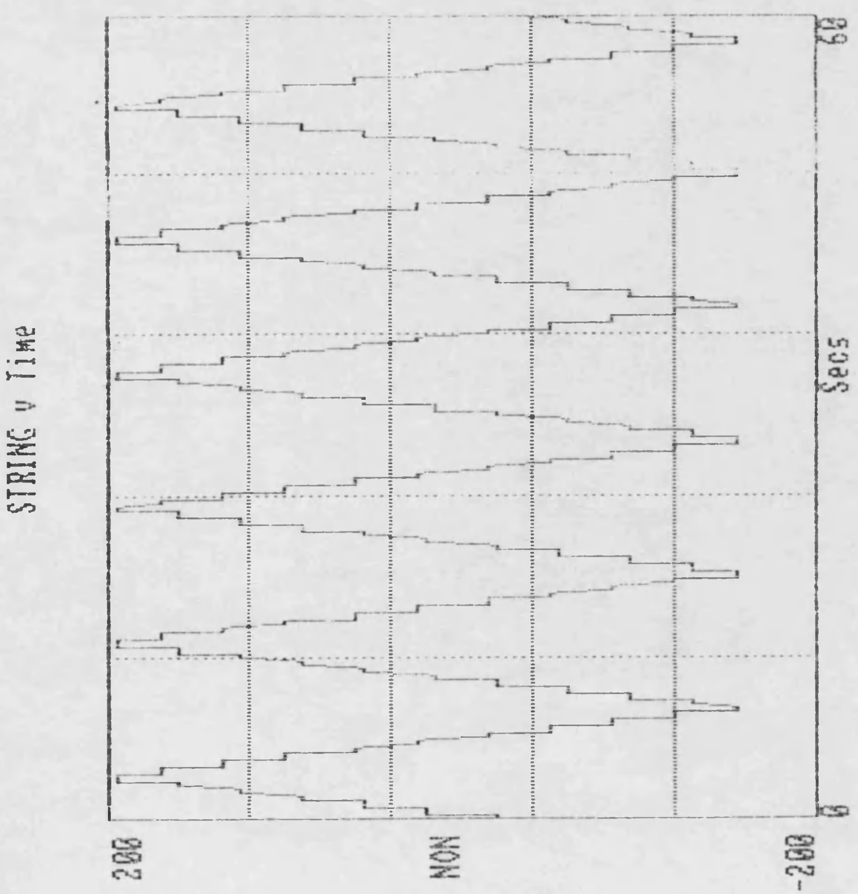
Conversion Factor = 0.0142299 mm/unit

Channel no. 13

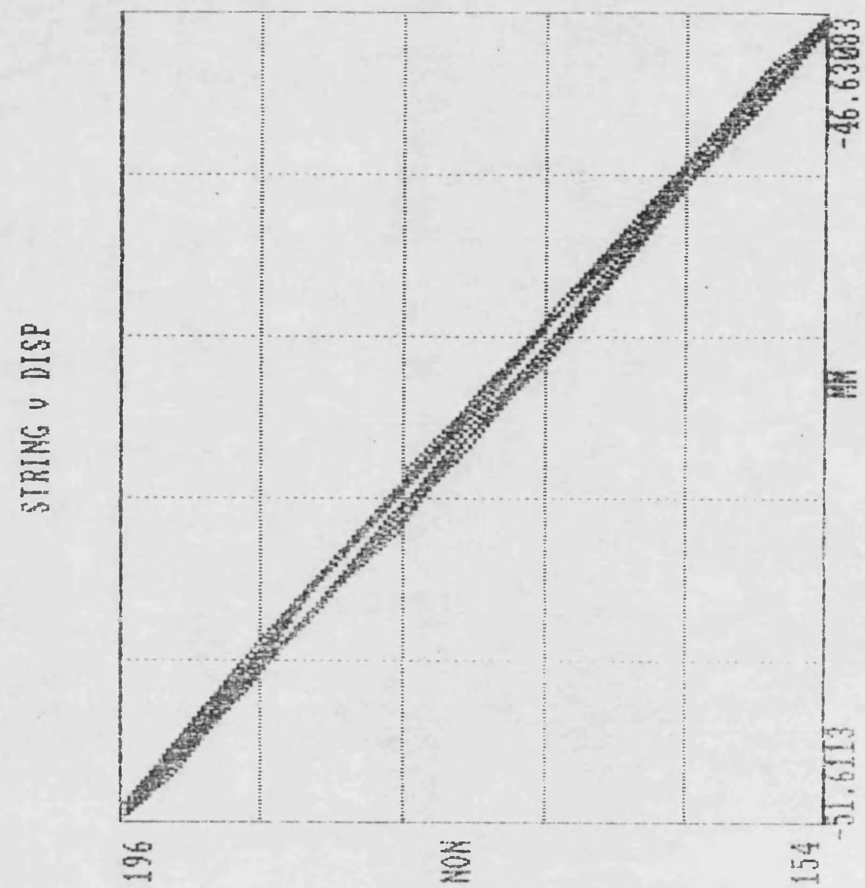
Induced Displacement [mm] = 4.98047

Response [ADU units] = 330

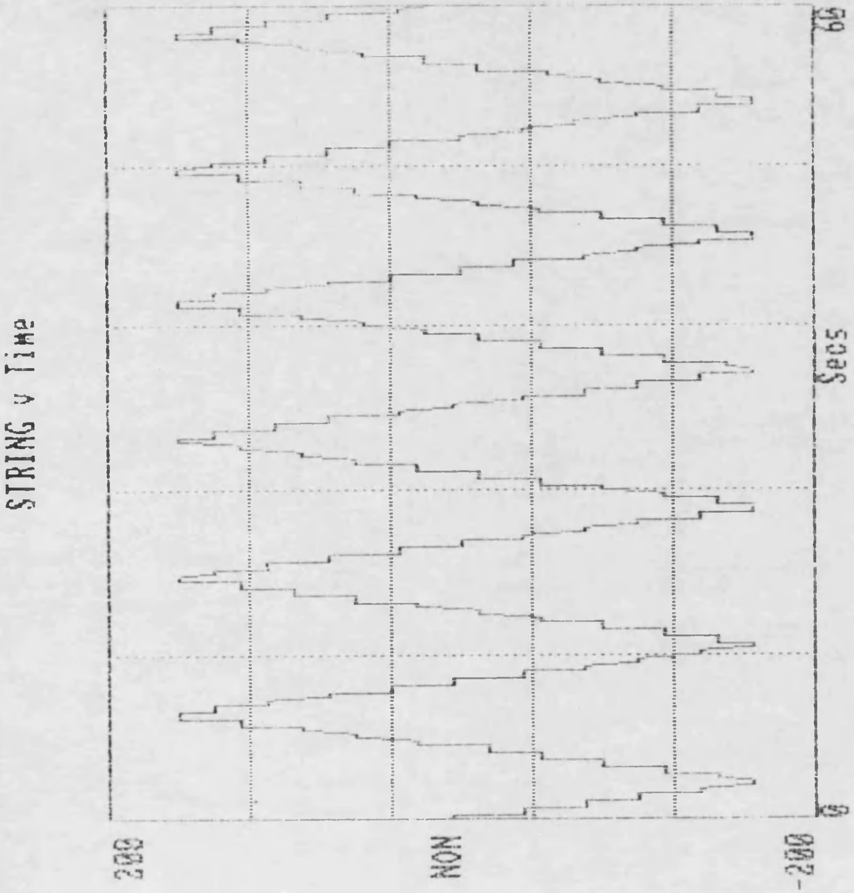
Conversion Factor = 0.01509 mm/unit



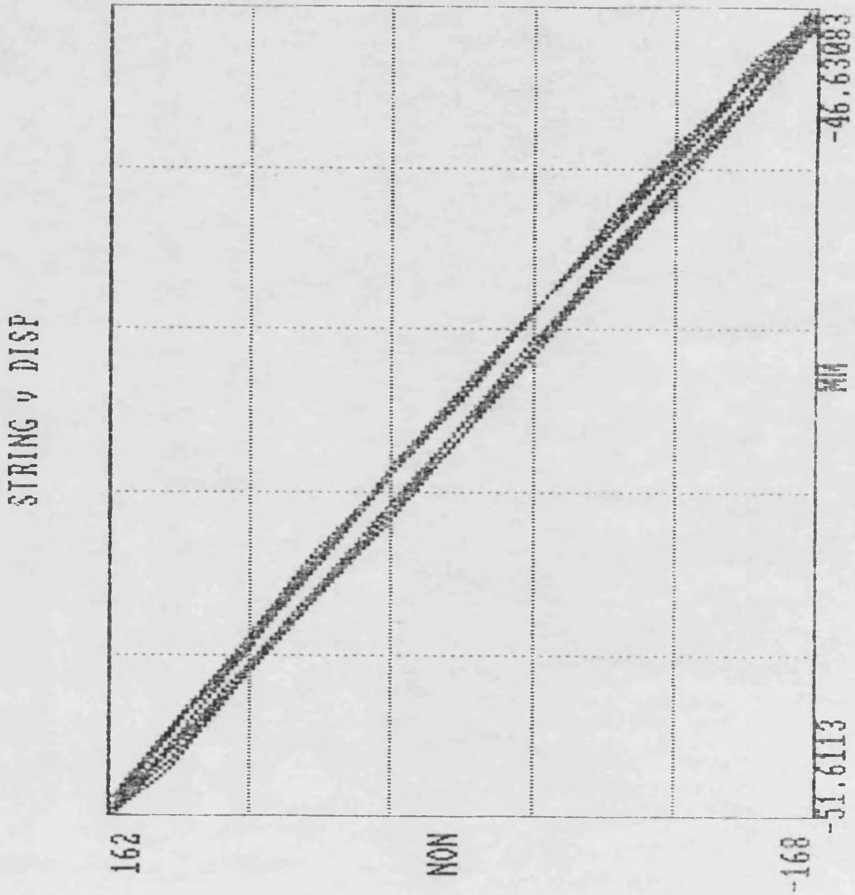
RING 2/14



RING 2/14



RING 2/13



RING 2/13

Strain Ring Conversion Factor Calculation Sheet

As mentioned in section 8.1, each 1/2 arrangement on each strain ring is identified by the Ring no. and the monitoring channel no.

Data taken from XY plots and numerical listings as appropriate.

RING No. 3

Channel no. 16

Induced Displacement [mm] = 5.27344

Response [ADU units] = 649

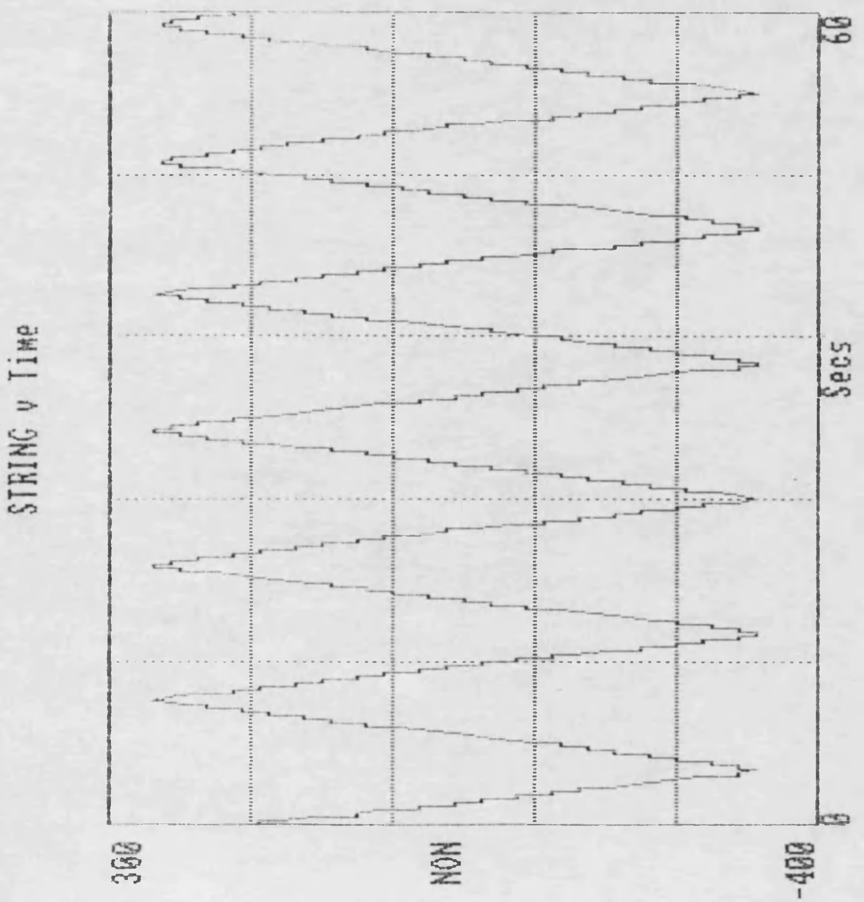
Conversion Factor = 8.125 x 10^{-3} mm/unit

Channel no. 12

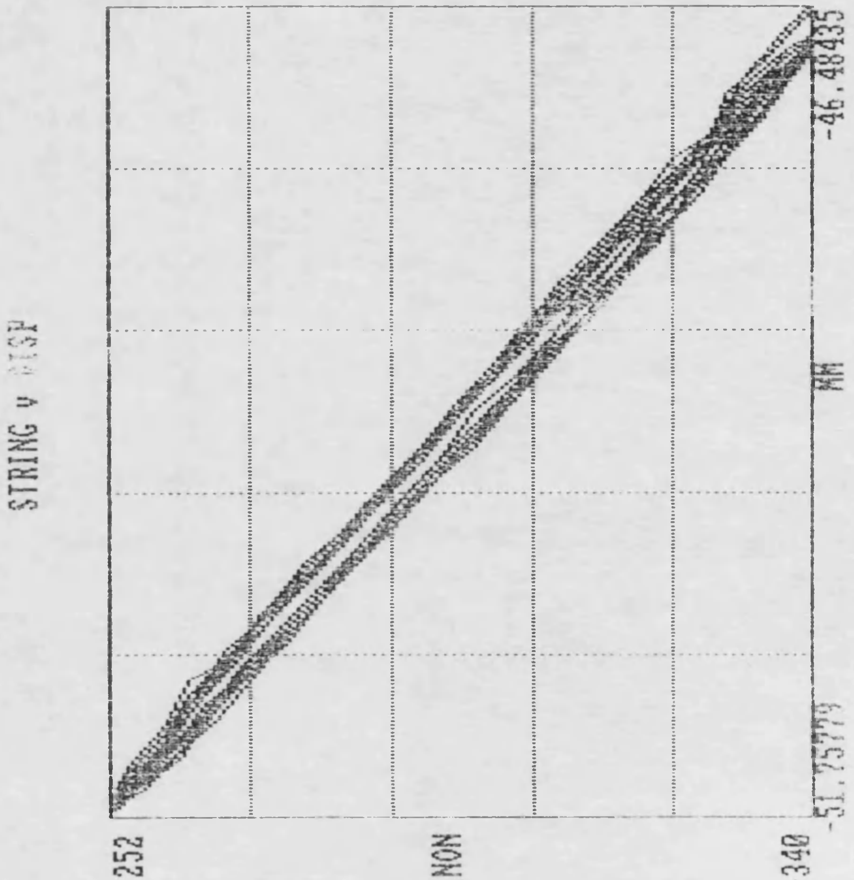
Induced Displacement [mm] = 5.27344

Response [ADU units] = 592

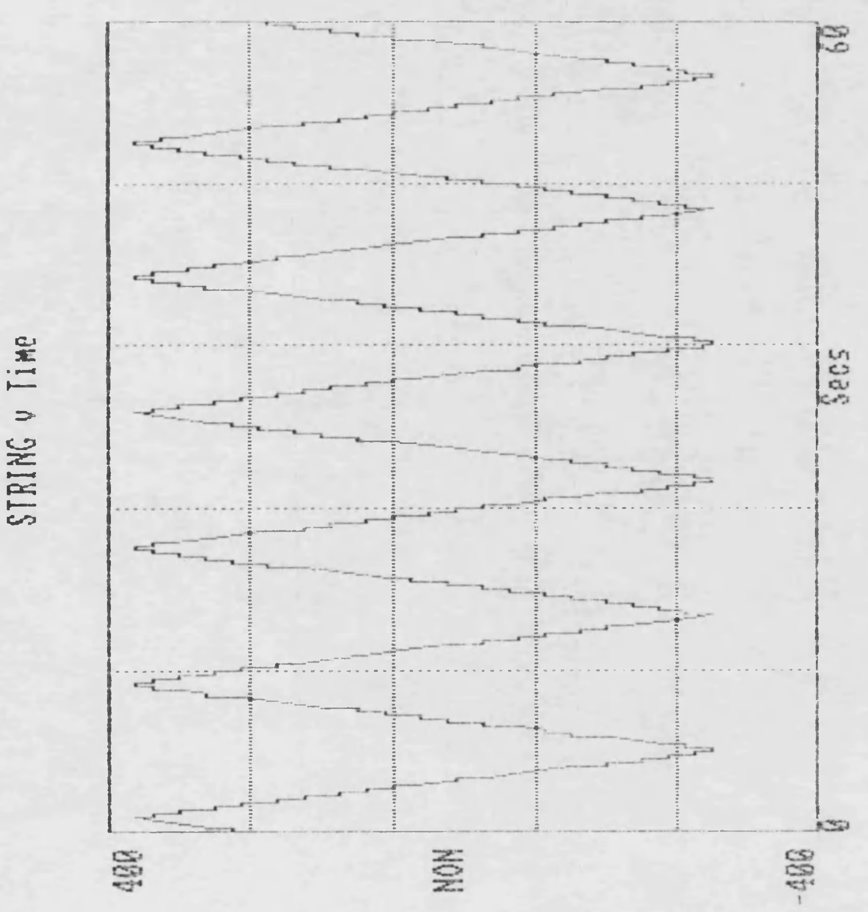
Conversion Factor = 8.9078 x 10^{-3} mm/unit



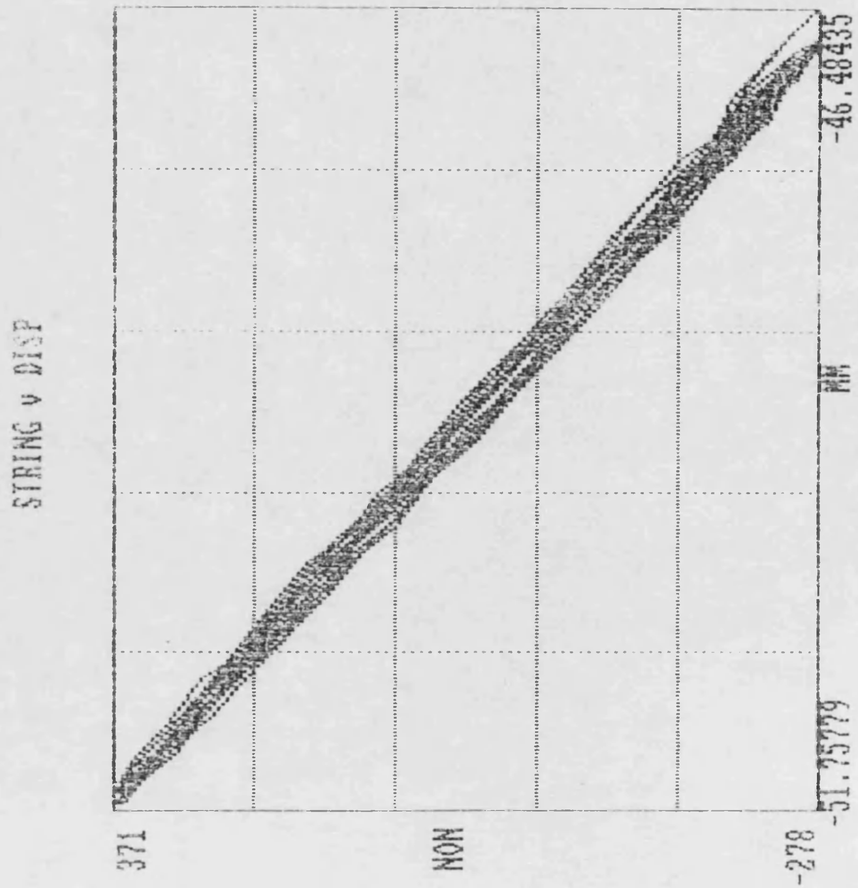
RING 3/12



RING 3/12



RING 3/16



RING 3/16

Strain Ring Conversion Factor Calculation Sheet

As mentioned in section 8.1, each 1/2 arrangement on each strain ring is identified by the Ring no. and the monitoring channel no.

Data taken from XY plots and numerical listings as appropriate.

RING No. 4

Channel no. 10

Induced Displacement [mm] = 4.98047

Response [ADU units] = 160

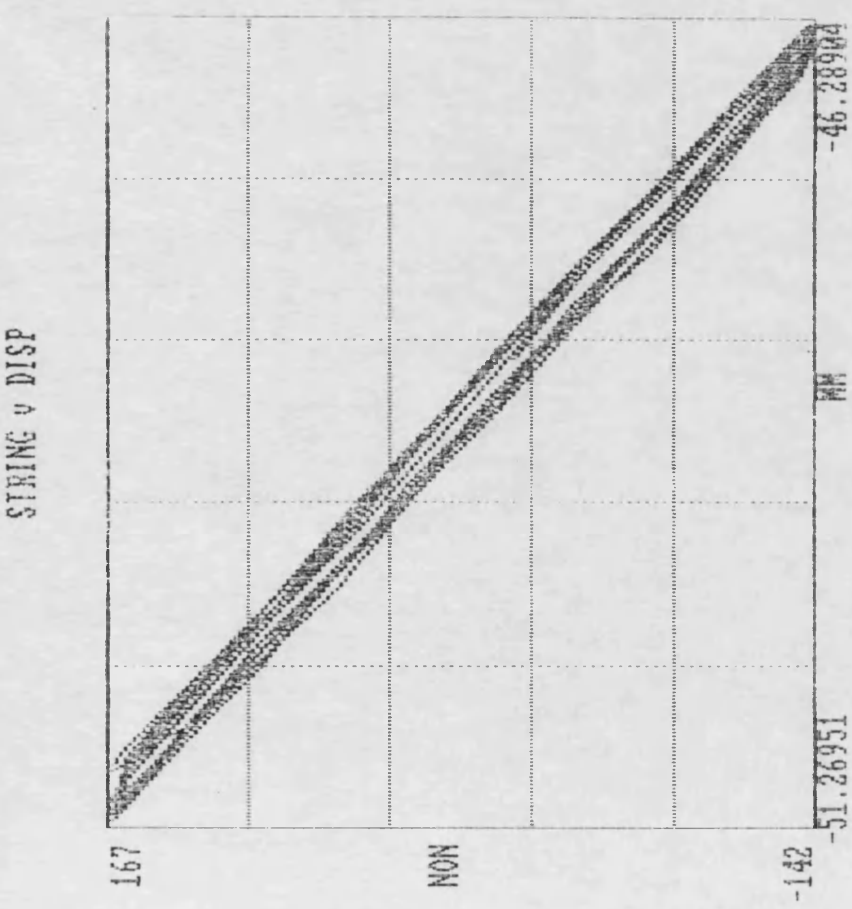
Conversion Factor = 0.03113 mm/unit

Channel no. 9

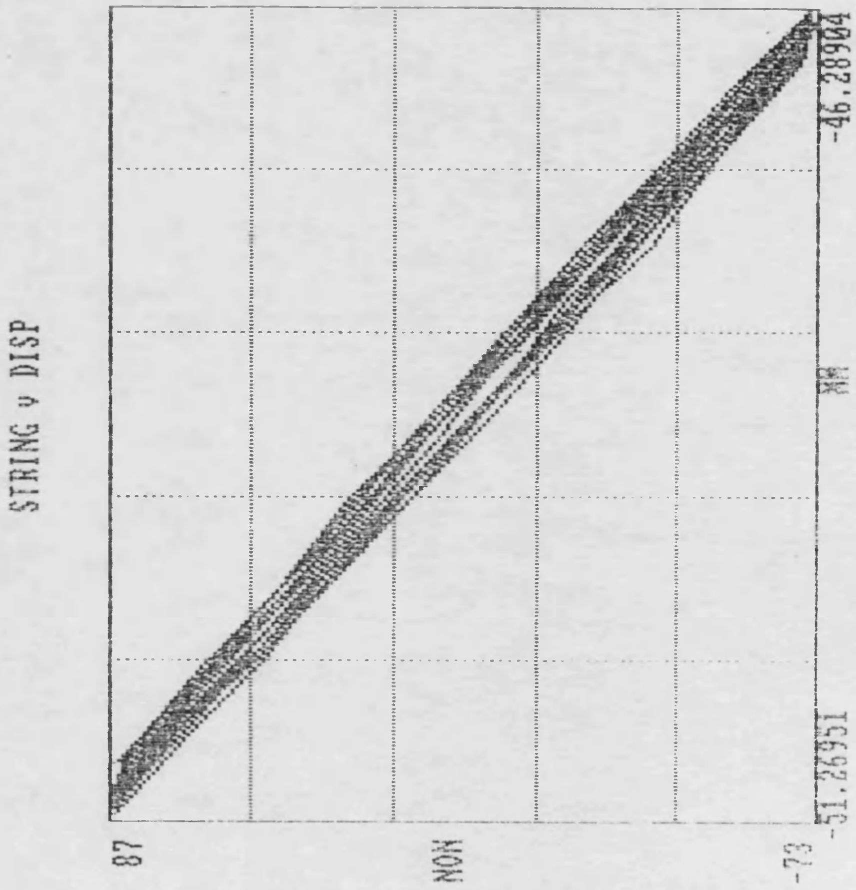
Induced Displacement [mm] = 4.98047

Response [ADU units] = 309

Conversion Factor = 0.016118 mm/unit

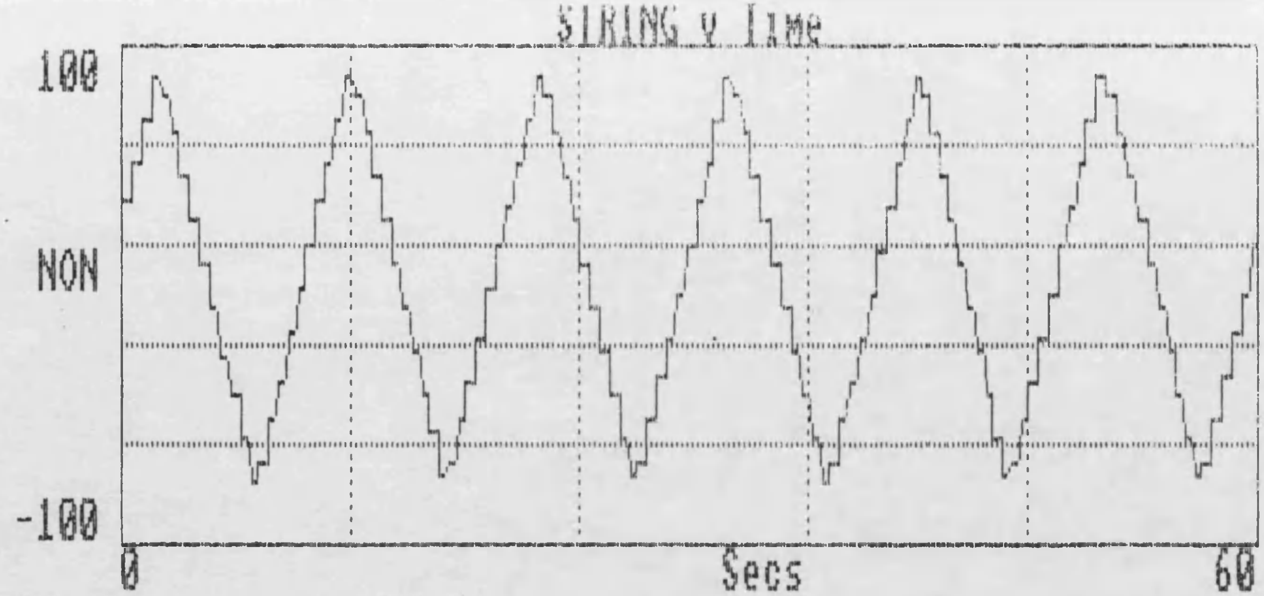


RING 4/9

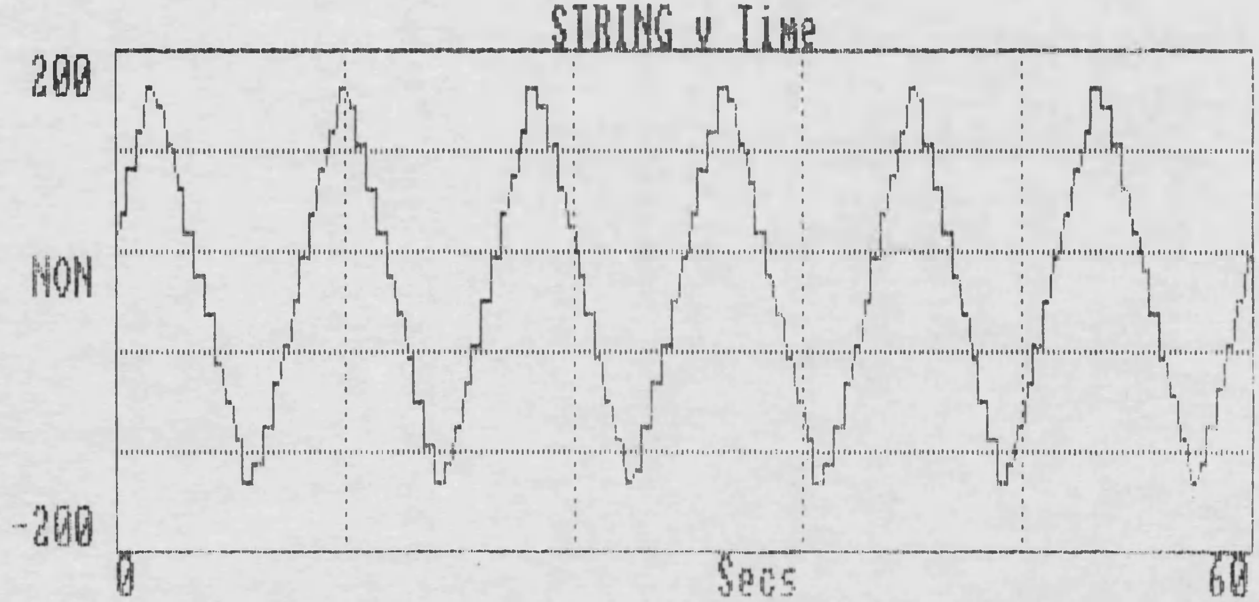


RING 4/10

RING 4/10



RING 4/9



Strain Ring Conversion Factor Calculation Sheet

As mentioned in section 8.1, each 1/2 arrangement on each strain ring is identified by the Ring no. and the monitoring channel no.

Data taken from XY plots and numerical listings as appropriate.

RING No. 5

Channel no. 16

Induced Displacement [mm] = 5.07812

Response [ADU units] = 727

Conversion Factor = 6.985×10^{-3} mm/unit

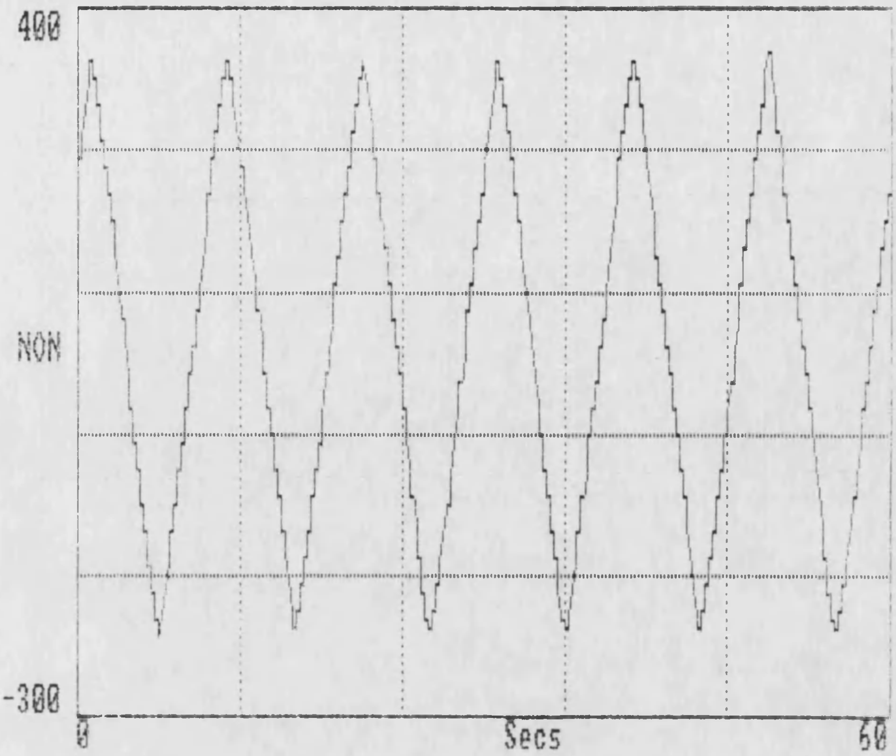
Channel no. 12

Induced Displacement [mm] = 5.07812

Response [ADU units] = 571

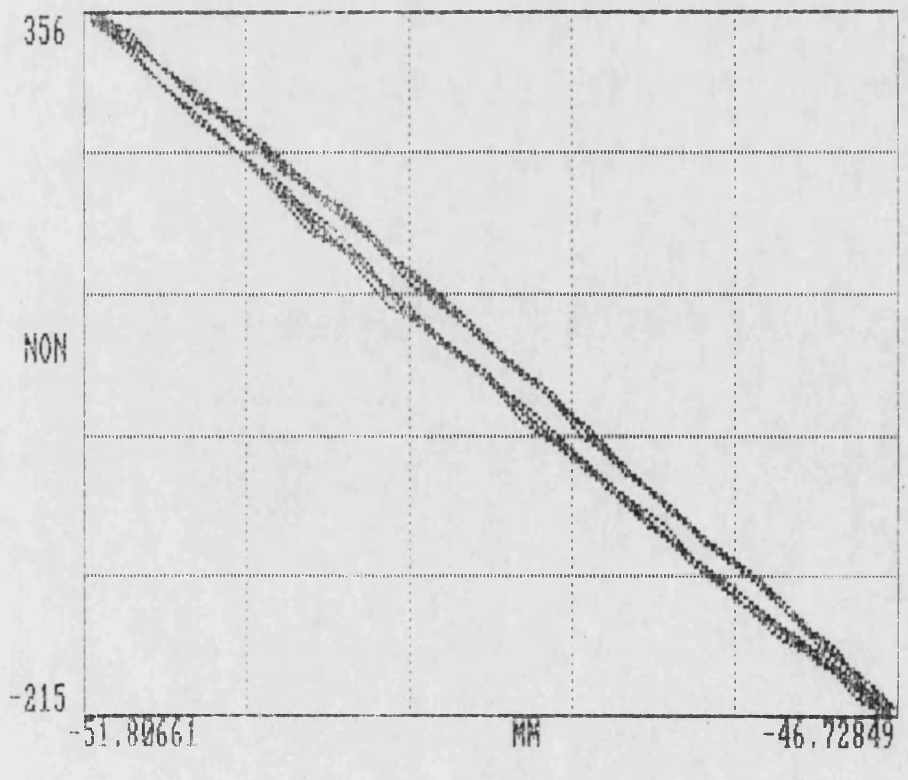
Conversion Factor = 8.893×10^{-3} mm/unit

STRING v Time

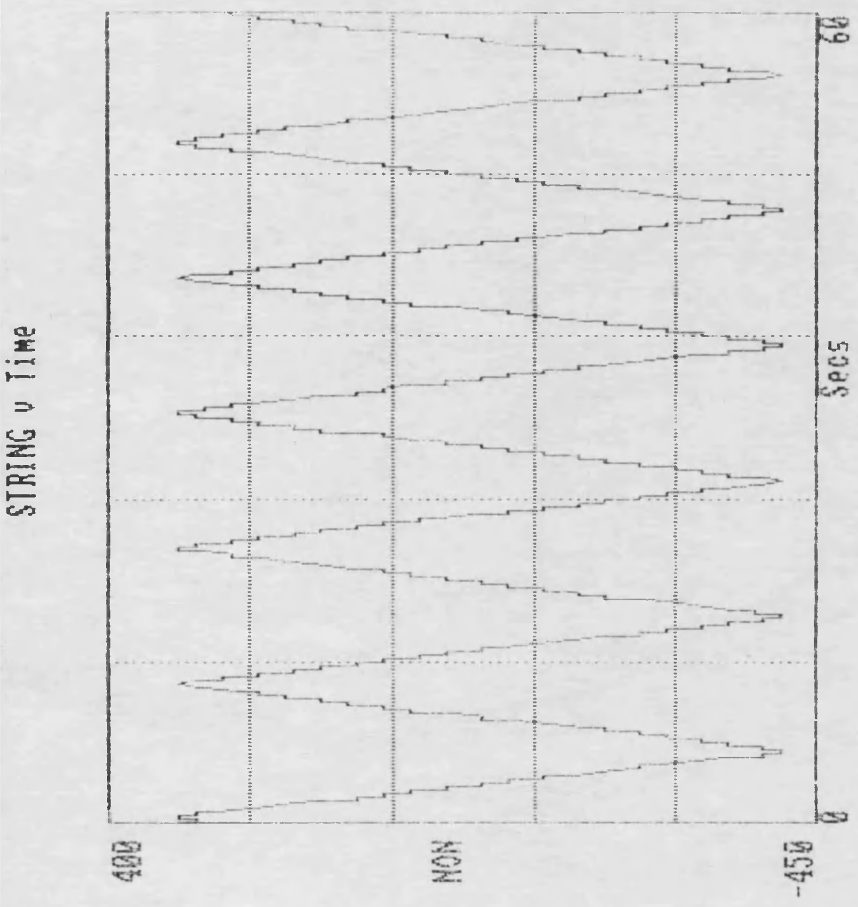


RING 5/12

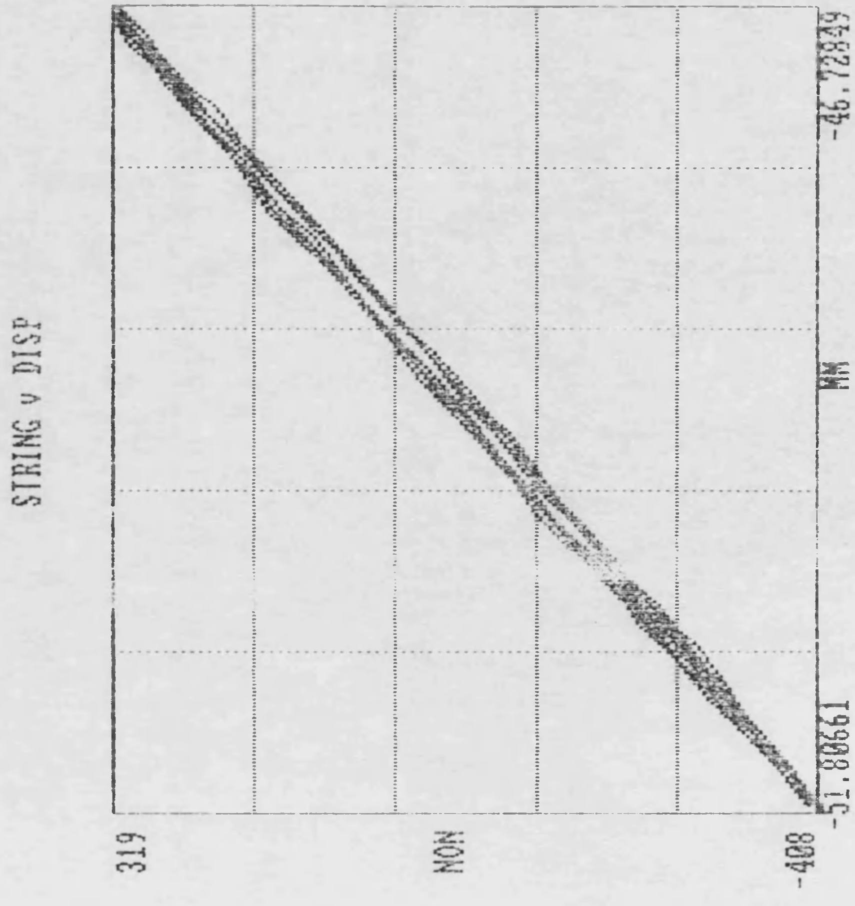
STRING v DISP



RING 5/12



RING 5/16



RING 5/16

Proprietary Transducer Calibration Certificates

1. Strain gauge displacement transducers.

2. Non indicating load cell.

3. DARTEC actuator load cells.

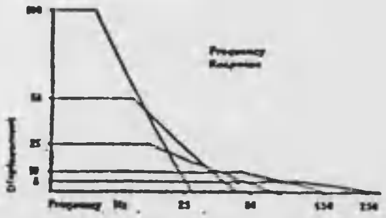
DISPLACEMENT TRANSDUCER

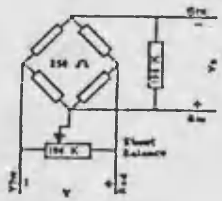
CALIBRATION REPORT

DATE 30.6.88

TRANSDUCER TYPE HLS 50 INPUT RED/YELLOW

SERIAL NO. 4020 OUTPUT BLUE/GREEN





EXCITATION VOLTS: AC OR DC BRIDGE 350 ohms NOMINAL

1,5 - 10 CONSTANT SHUNT 100k ohms NOMINAL

25 max: pulsed

CALIBRATION DATA

GAUGE FACTOR SET 2.0 TEST VOLTS 5.21 VDC TEMPERATURE 20 °C

F S SPINDLE DISPLACEMENT 51.550 MM. NON LINEARITY 0.05 ± % FS

STRAIN SENSITIVITY 143 x 10^{-6} /MM. VOLTS SENSITIVITY 3.7 mV/V

OPERATING NOTES

CLEAN OPERATING SPINDLE WITH RESIDUE-FREE SOLVENT/INHIBITOR TYPE CLEANER 111-TRICHLOROETHANE OR SIMILAR.

FOR REPETITIVE CYCLIC OPERATION LIGHTLY LUBRICATE ONLY WITH GENERAL PURPOSE SYNTHETIC INSTRUMENT OIL WINDSOR L 245X (MIL-L-6085A) OR EQUIVALENT, DO NOT OVER LUBRICATE.

USE SOFT JAW CLAMPS TO GRIP SPINDLE WHEN CHANGING ANVIL.

CLAMP TRANSDUCER ON BODY DIAMETER ONLY.

Welwyn Strain Measurement
Armstrong Road, Basingstoke, Hants. RG24 0QA
Telephone: Basingstoke (0256) 462131 Telex: 858520
Fax: (0256) 471441 A Crystalate Company

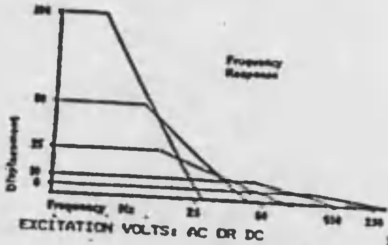
DISPLACEMENT TRANSDUCER

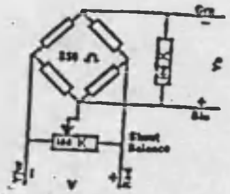
CALIBRATION REPORT

DATE 23.8.88

TRANSDUCER TYPE HS 100 INPUT RED/YELLOW

SERIAL NO. 5020 OUTPUT BLUE/GREEN





EXCITATION VOLTS: AC OR DC BRIDGE 350 ohms NOMINAL

1,5 - 10 CONSTANT SHUNT 100k ohms NOMINAL

25 max: pulsed

CALIBRATION DATA

GAUGE FACTOR SET 2.0 TEST VOLTS 5.21 VDC TEMPERATURE 20 °C

F S SPINDLE DISPLACEMENT 102.1 MM. NON LINEARITY 0.2 ± % FS

STRAIN SENSITIVITY 105 x 10^{-6} /MM. VOLTS SENSITIVITY 5.4 mV/V

OPERATING NOTES

CLEAN OPERATING SPINDLE WITH RESIDUE-FREE SOLVENT/INHIBITOR TYPE CLEANER 111-TRICHLOROETHANE OR SIMILAR.

FOR REPETITIVE CYCLIC OPERATION LIGHTLY LUBRICATE ONLY WITH GENERAL PURPOSE SYNTHETIC INSTRUMENT OIL WINDSOR L 245X (MIL-L-6985A) OR EQUIVALENT, DO NOT OVER LUBRICATE.

USE SOFT JAW CLAMPS TO GRIP SPINDLE WHEN CHANGING ANVIL.

CLAMP TRANSDUCER ON BODY DIAMETER ONLY.

Welwyn Strain Measurement
Armstrong Road, Basingstoke, Hants. RG24 0QA
Telephone: Basingstoke (0256) 462131 Telex: 858520
Fax: (0256) 471441 A Crystalate Company

CHASE MEASUREMENTS

CHASE MEASUREMENTS LTD
THEATRE STREET
WARWICK CV34 4DP
Telephone: (0926) 490088
FAX 0926 410167
TRANSDUCER & SYSTEMS ENGINEERS

CALIBRATION CERTIFICATE
****

CHASE MEASUREMENTS LTD
THEATRE STREET
WARWICK
CV34 4DP

Telephone: (0926) 490088
Fax: (0926) 410167

Your O.N.	Our O.N.	Date
362578	CM284	28/10/88

Model	Accuracy	Serial Nº
CCA 10TONNE	0·2 %	CCA/10/134

Cable Colour Coding

Output 2·00 mV/V

Red + Excitation
Blue - Excitation

Green − Output
Yellow + Output

This load cell is made to the specifications laid down in our technical information.

CERTIFICATE OF CALIBRATION

ISSUED BY THE CALIBRATION FACILITIES OF DARTEC LIMITED

DATE OF ISSUE 19th May, 1992 SERIAL NUMBER 01345/A

NAMAS

CALIBRATION No. 0135

DARTEC / DARTEC LIMITED

BALDS LANE · LYE · STOURBRIDGE
WEST MIDLANDS · ENGLAND · DY9 8SH

Tel (0384) 892363
Tlx 336902 DARTEC
Fax (0384) 892772

PAGE 1 OF 1 PAGES

APPROVED SIGNATORY

Head of Laboratory:- R. E. M. Ball

Issued to:- UNIVERSITY OF BATH

Location:- Department of Architecture and Building Engineering, Bath

Description:- A force measuring system which, when used, with an actuator, within a test rig, can be regarded as a range of a testing machine. The load cell has a maximum capacity of 50kN and the associated indicator displays 0 - 50kN.

Identification:- Load Cell - 87167, Indicator - 87167/E2

Date of Calibration:- 28th April, 1992

The above force measuring system has been verified to the British Standard 1610:Part I:1985, using the equipment listed below, which complied with Clause 3.3 of the standard. To facilitate the verification, the load cell and verification equipment were mounted in series on the actuator piston and the assembly positioned within a rig. The indicated force method was used to effect the verification and the maximum reading facility was not used.

20kN:- Load Cell, No:- 46148, Indicator No:- 46143, Manufactured by Interface Inc., NPL Reference No:- 08C011/91085/LL105/17, dated 4th April, 1991

100kN:- Load Cell No:- K011171. Indicator No:- K011171, Manufactured by Baldwin Lima Hamilton Corporation, NPL Reference No:- 08C011/90279/LL125/3, dated 26th October, 1990.

The temperature at the time of verification was 20°C
The machine indicator resolution was 0.001kN

The force measuring system complied with the requirements of the British Standard for the following grading:-

Grade 1.0 Tension 50 kN down to 1kN
Grade 1.0 Compression 50 kN down to 1kN

The uncertainties are for a confidence probability of not less than 95%

CERTIFICATE OF CALIBRATION

ISSUED BY THE CALIBRATION FACILITIES OF DARTEC LIMITED

DATE OF ISSUE 19th May, 1992 SERIAL NUMBER 01344

NAMAS

CALIBRATION No. 0135

DARTEC / DARTEC LIMITED

BALDS LANE · LYE · STOURBRIDGE
WEST MIDLANDS · ENGLAND · DY9 8SH

Tel (0384) 892363
Tlx 336902 DARTEC
Fax (0384) 892772

PAGE 1 OF 1 PAGES

APPROVED SIGNATORY

Head of Laboratory:- R. E. M. Ball

Issued to:- UNIVERSITY OF BATH

Location:- School of Architecture and Building Engineering, Bath

Description and Identification:- A universal, materials, testing machine of 100kN maximum capacity

Machine Type:- DARTEC M1000/RK

Serial Number:- 88343/B

Date of Calibration:- 28th April, 1992

The above testing machine has been verified to the British Standard 1610:1985, using the equipment listed below, which complied with Clause 3.3 of the standard.

The indicated force method was used to effect the verification and the maximum reading facility was not used.

20kN:- Load Cell, No:- 46148, Indicator No:- 46143, Manufactured by Interface Inc., NPL Reference No:- 08C011/91085/LL105/17, dated 4th April, 1991

100kN:- Load Cell No:- K011171. Indicator No:- K011171, Manufactured by Baldwin Lima Hamilton Corporation, NPL Reference No:- 08C011/90279/LL125/3, dated 26th October, 1990.

The temperature at the time of verification was 20°C
The machine indicator resolution was 0.001kN

The machine complied with the requirements of the British Standard for the following grading:-

Grade 1.0 Tension 100 kN down to 1 kN

Grade 1.0 Compression 100 kN down to 1 kN

The uncertainties are for a confidence probability of not less than 95%

APPENDIX 5 Test Data

Contents:

1. 1st stage 'calibration' tests.
2. 2nd stage 'calibration' tests.
3. Large granular material tests in 254mm cell.
4. Preliminary dynamic data. Verification purposes only.

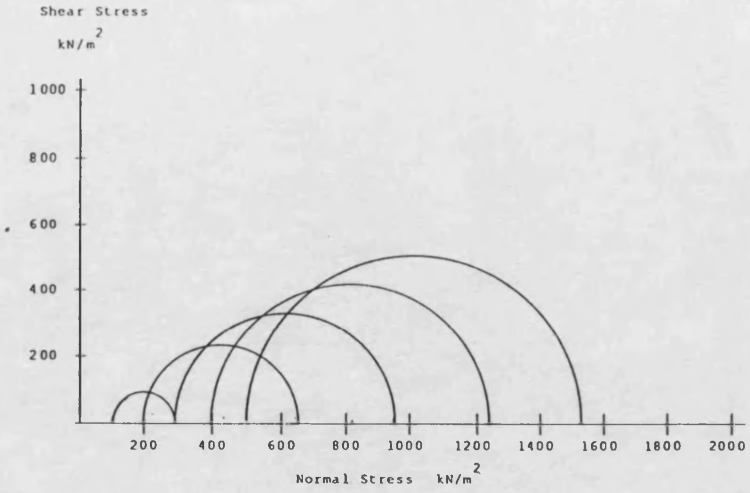
Test Results for the 1st stage static calibration tests, as detailed in section 8.3.4 and 8.3.5. Sample sizes - 38mm, 100mm, 254mm.

Includes;

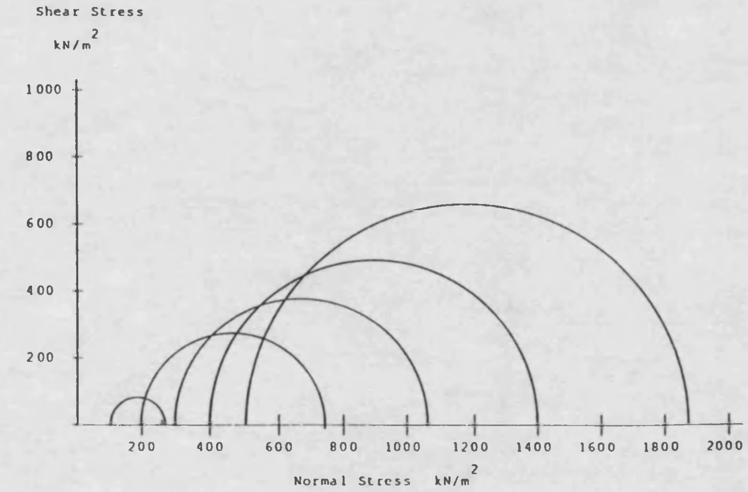
1. Summary table.
2. Multi stage plots of raw data using area correction method.
3. Derived Mohr circle plots.

SUMMARY TABLE FOR INITIAL CALIBRATION TESTS

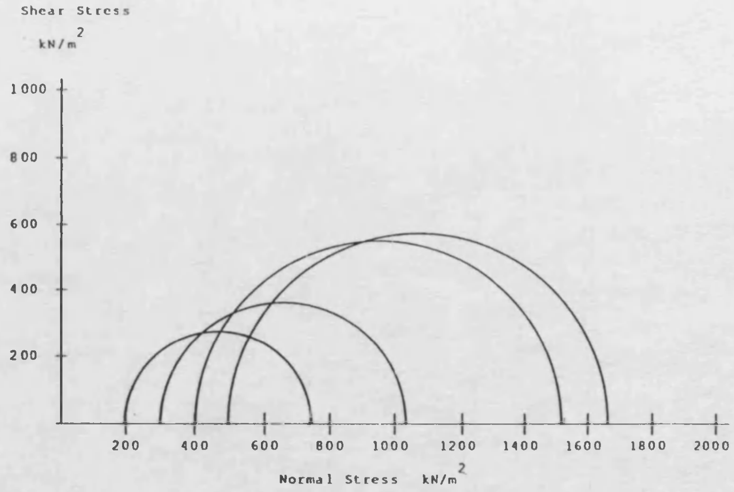
Test No.	Sample Dia. mm	material	mass kg	σ_3 kN/m^2	σ_1 kN/m^2	ϕ_{calc} (°)	ϕ_{plot} (°)
1	38	'fine' 52/100 grade	0.112	100 200 300 400 500	292 641 941 1241 1528	29 32 34 31 30	31
2	38	'medium' Holm sand	0.123	100 200 300 400 500	360 740 1074 1397 1695	34.4 35 34.3 33.7 33	34
3	38	'course' 14/25 grade	0.120	200 300 400 500	725 1058 1340 1674	34.6 33.9 32.7 32.7	33
4	100	'fine' 52/100 grade	2.193	200 300 400 500	841 1225 1590 1918	38 37.3 36.7 36	37
5	100	'medium' Holm sand	2.318	200 300 400 500	1026 1443 1788 2093	42.3 41 39.4 37.9	38
6	100	'course' 14/25 grade	2.248	100 200 300 400 500	437 881 1219 1583 1895	35 39 37.2 36.6 35.6	37
7	254	'fine 52/100 grade	27.497	100 200 300	445 891 1267	39.3 39.3 38.1	38
8	254	'medium' Holm sand	29.962	100 200 300	534 1000 1385	43.2 41.8 40.1	40
9	254	'course' 14/25 grade	28.90	100 200 300	494 891 1454	41.6 39.3 41.1	40



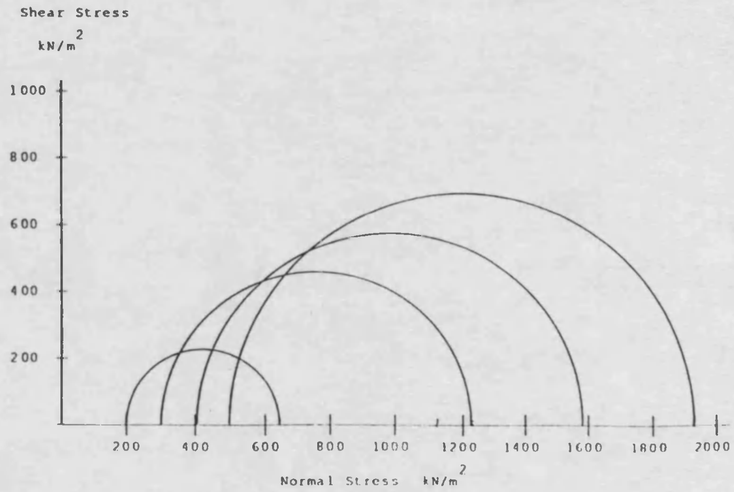
Mohrs circle plot for Test No. 1



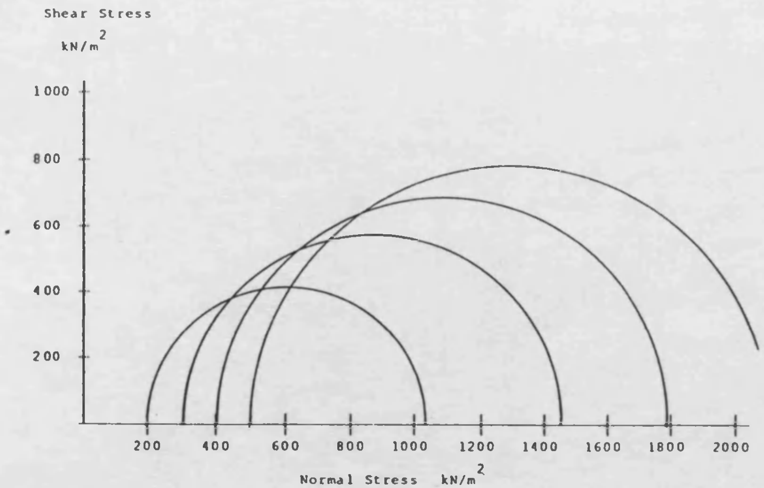
Mohrs circle plot for Test No. 2



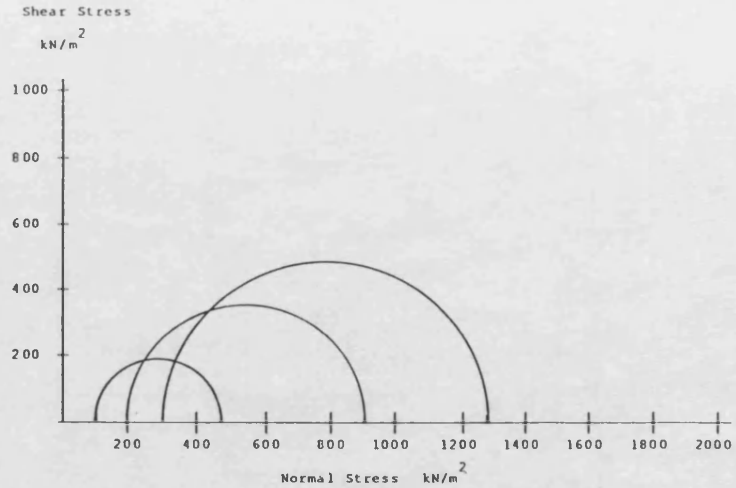
Mohrs circle plot for Test No. 3



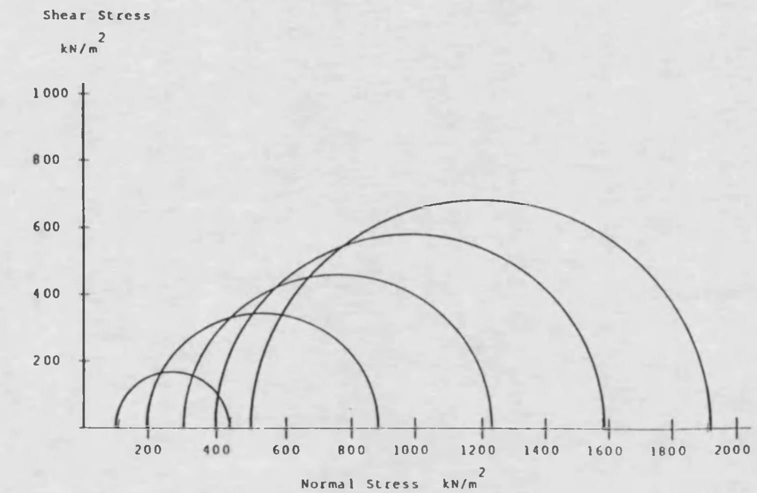
Mohrs circle plot for Test No. 4



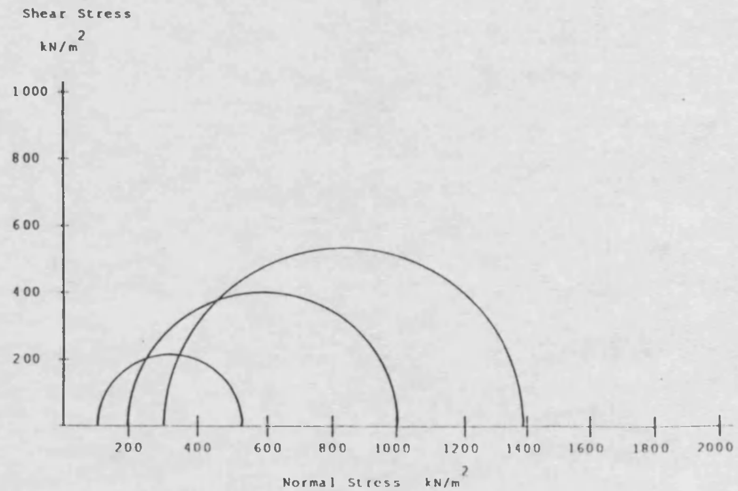
Mohrs circle plot for Test No. 5



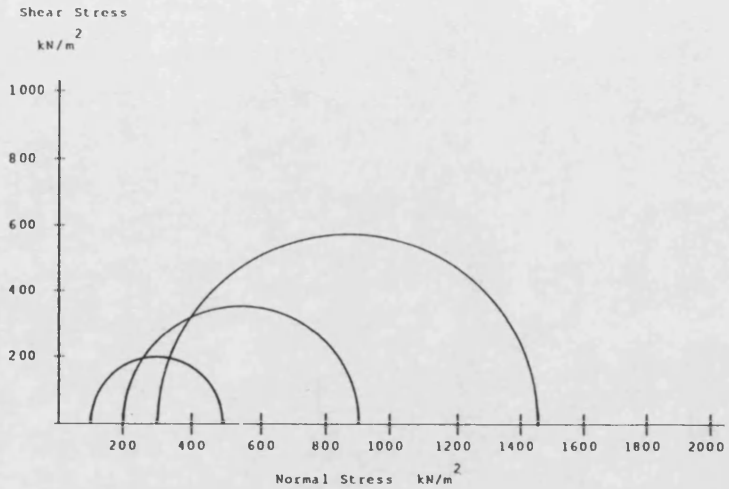
Mohrs circle plot for Test No. 7



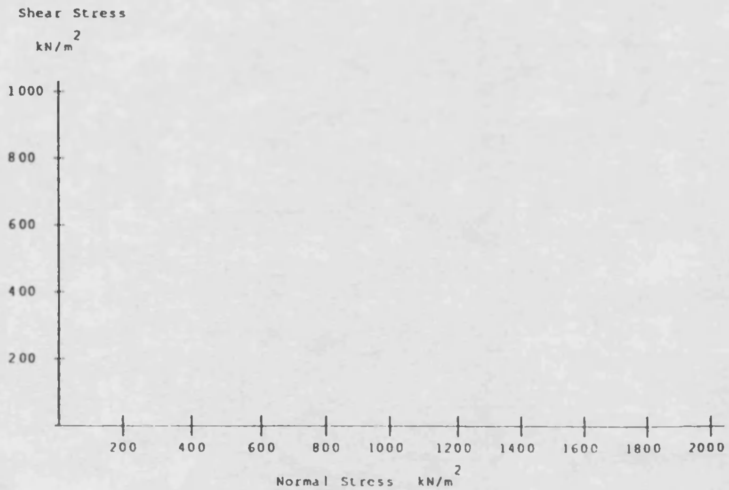
Mohrs circle plot for Test No. 6



Mohrs circle plot for Test No. 8



Mohrs circle plot for Test No. 9



Mohrs circle plot for Test No.

CONVERSION FACTORS FOR AREA CORRECTION METHOD

The area correction procedure, for plotting the readings during load application, provides an indication of the **stress** response of the sample, thus yielding information allowing decisions on when to increase the cell pressure in the multi-stage test method.

Assuming constant volume, knowledge of the rate of axial compression, initial sample dimensions, and load recording device, area correction paper can be produced taking account of the increase in area throughout the test. This can be understood by appreciating that as the test proceeds, the sample compresses and therefore the cross sectional area increases. As a consequence, as the test continues an increased load is necessary to maintain the same stress accross the sample.

For the data in this report, the stress is read horizontally accross each of the plots. The sloping lines indicate the load response. In order to convert the vertical axis to stress the following conversion factors are utilised.

38mm samples : initial sample area = 1.134×10^{-3} m^2

proving ring conversion = 5.890 N/div

(2000 lb ring, ref. no. 3561)

Conversion factor = 5.194 kN/m^2

100mm samples: initial sample area = 7.854×10^{-3} m^2

proving ring conversion = 25.96 N/div

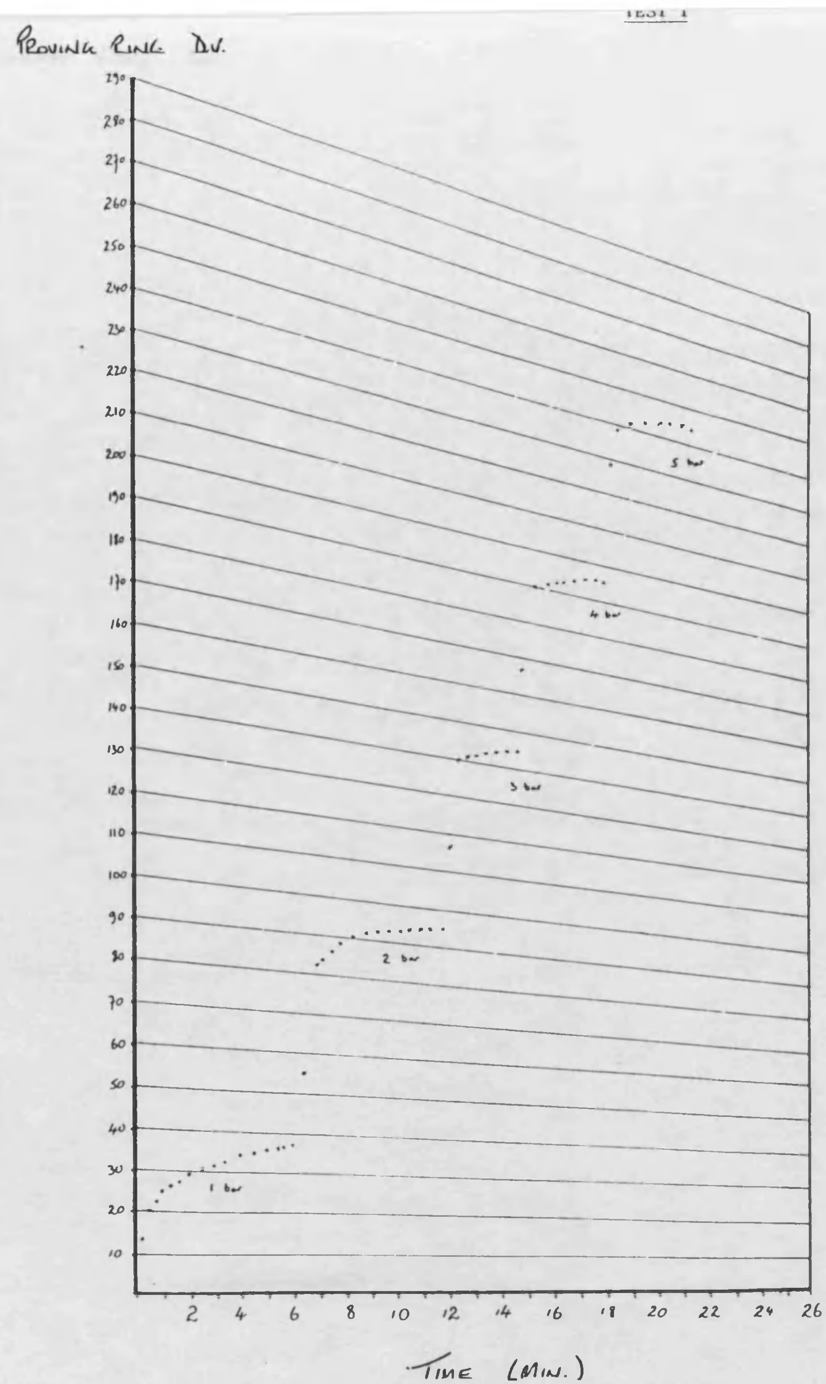
(6000 lb ring, graphical conversion)

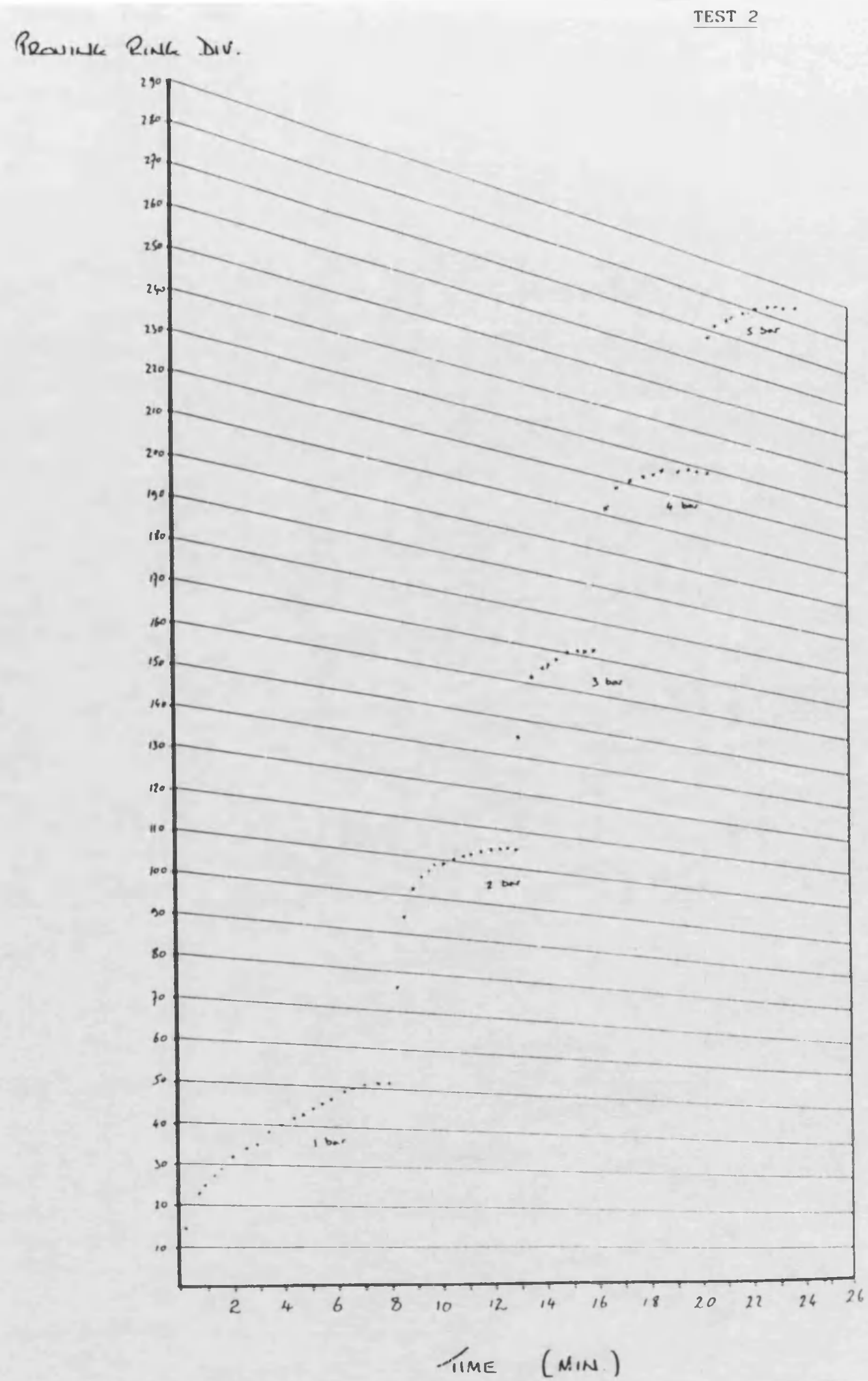
conversion factor = 3.305 kN/m^2

254mm samples: initial sample area = 0.05067 m^2

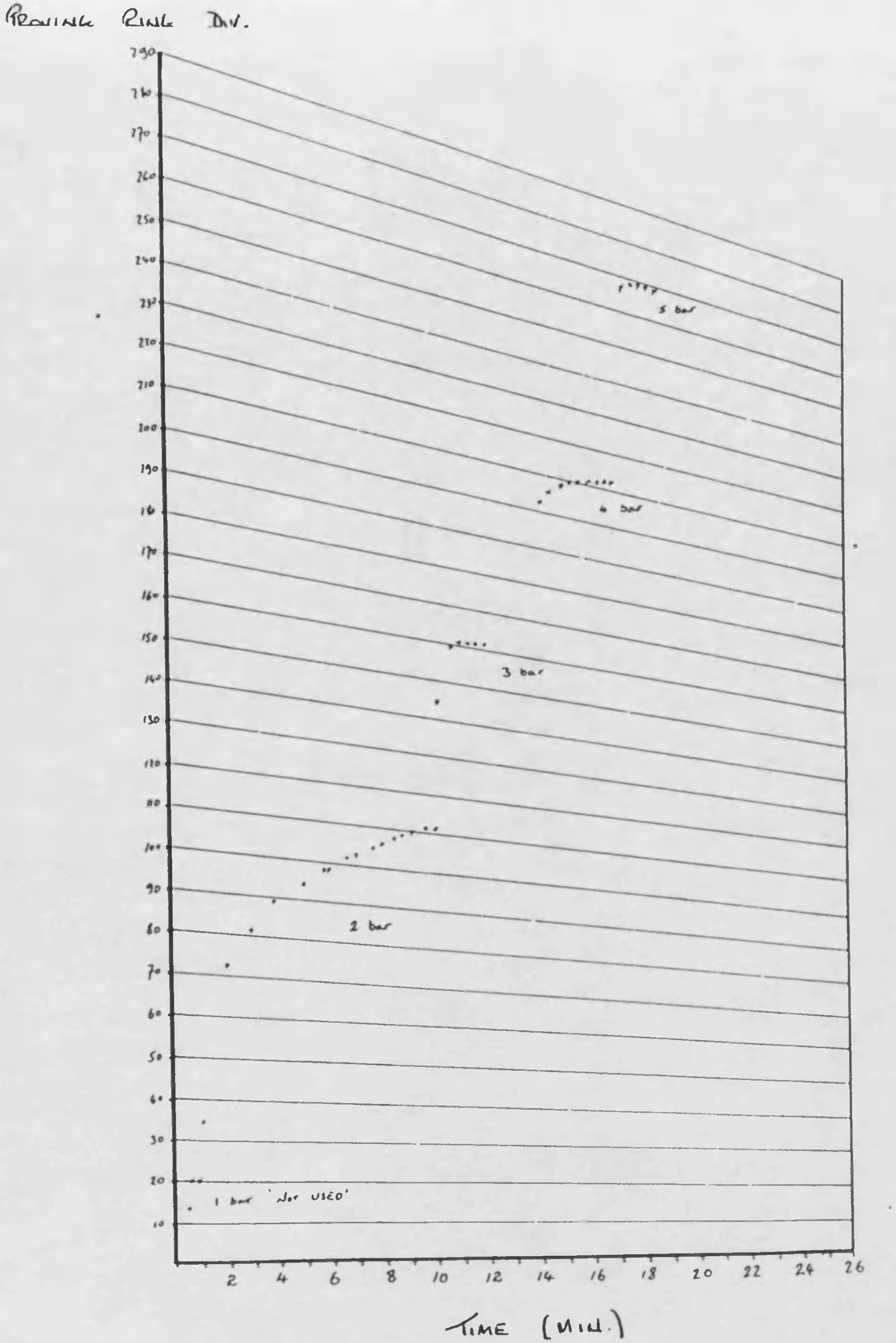
load recorded directly in kN.

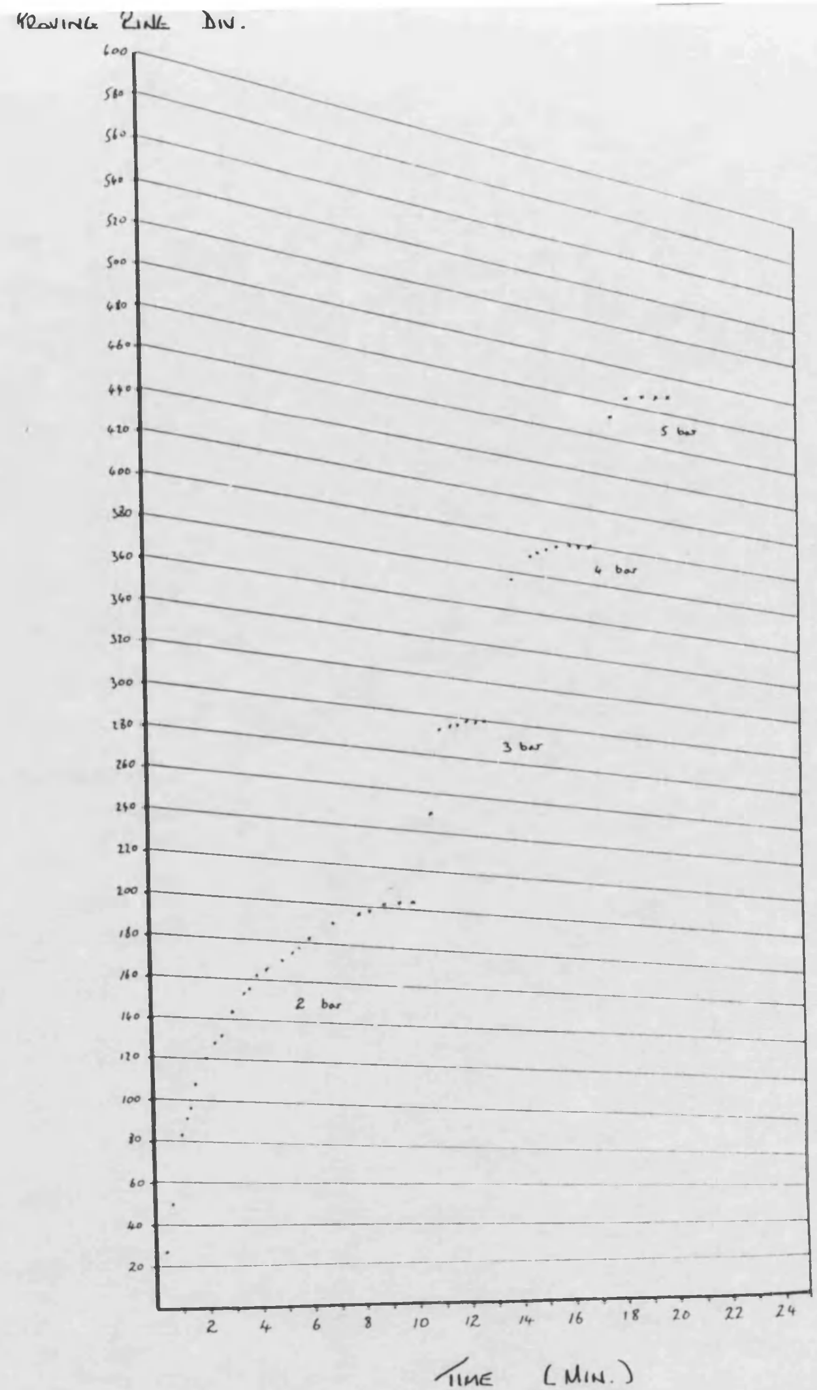
conversion factor = 19.735 kN/m^2

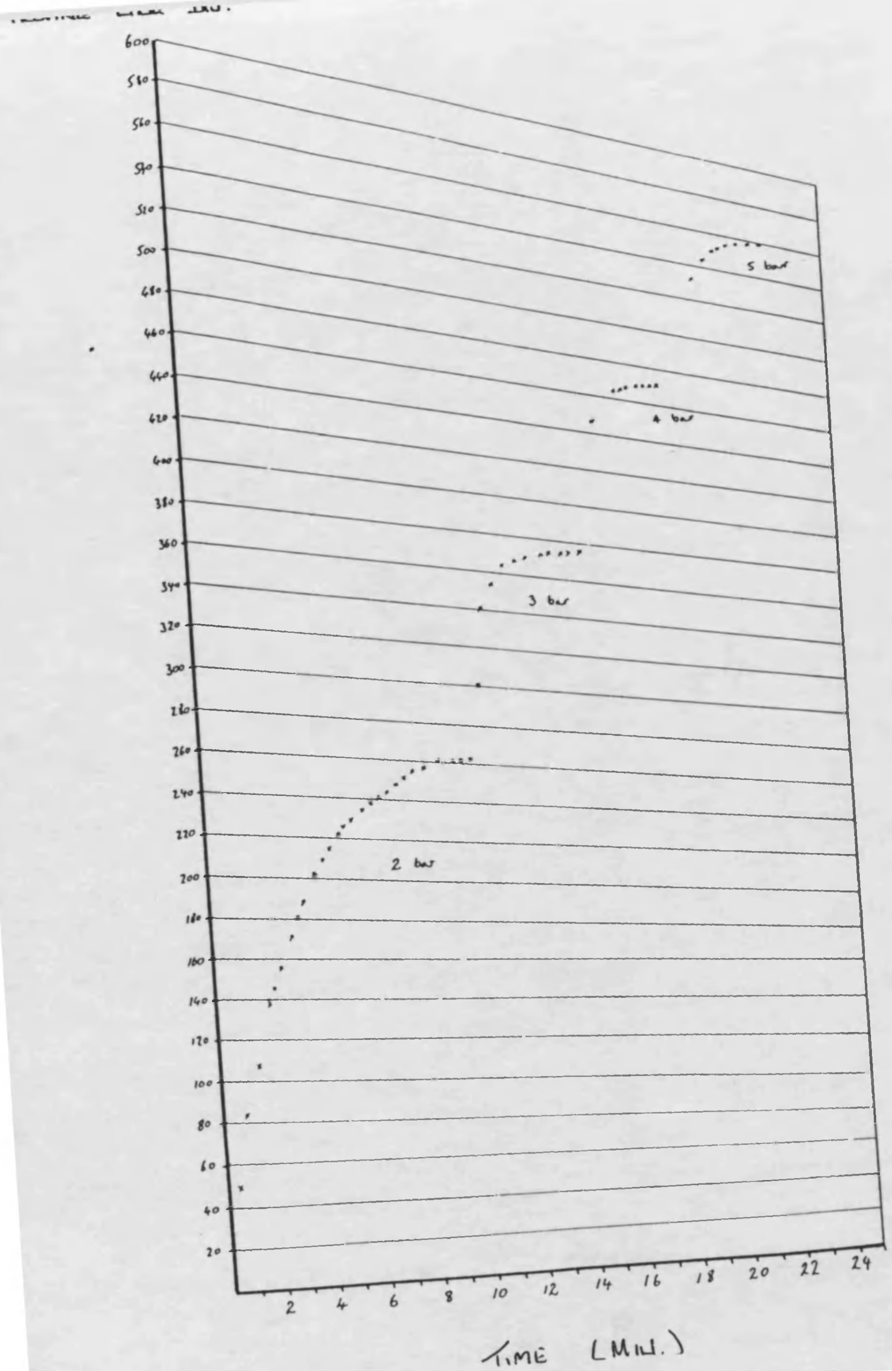

TEST 1
PROVING RING DIV.
1 bar
2 bar
3 bar
4 bar
5 bar
TIME (MIN.)

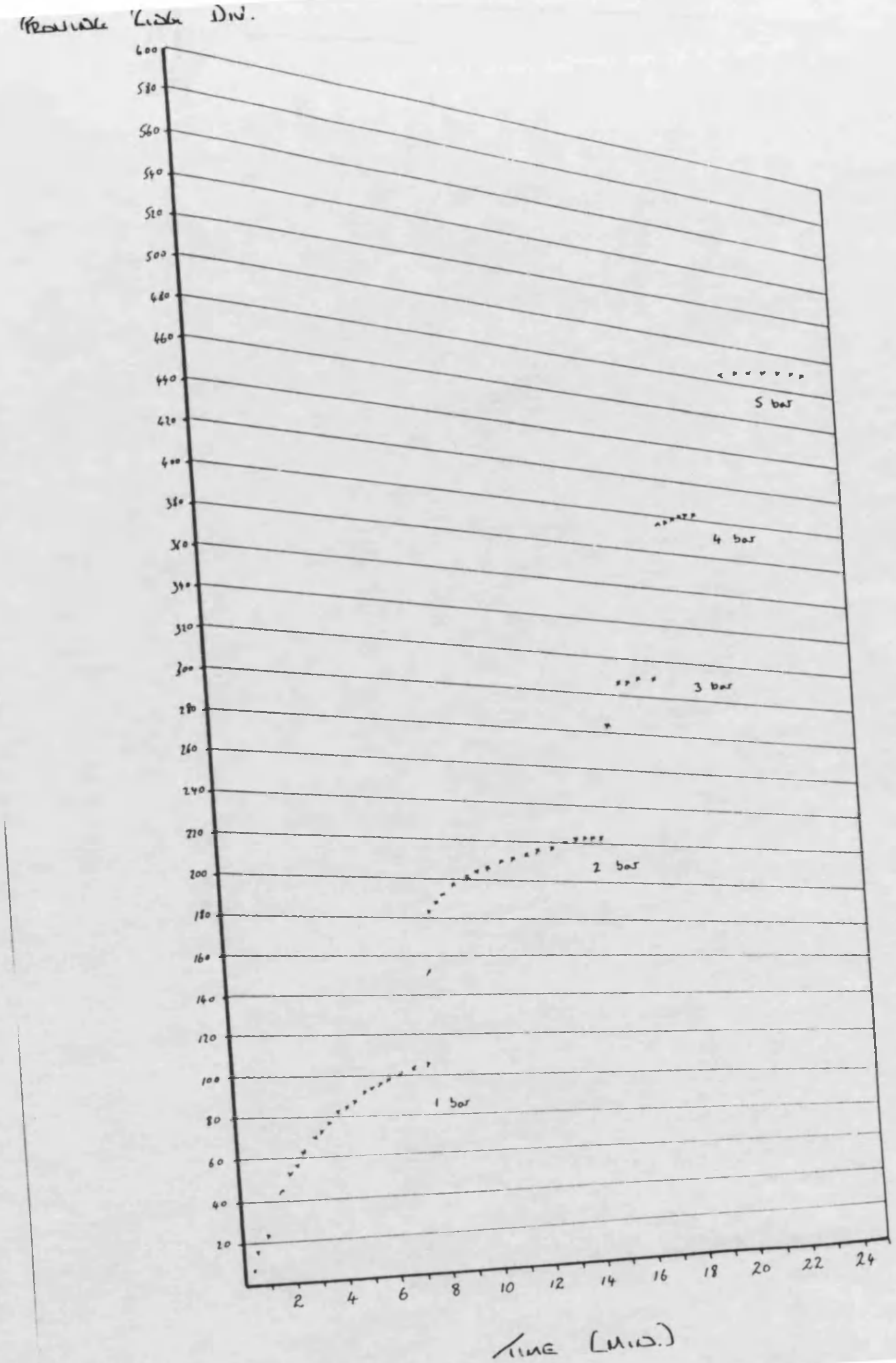

TEST 2
PROVING RING DIV.
1 bar
2 bar
3 bar
4 bar
5 bar
TIME (MIN.)

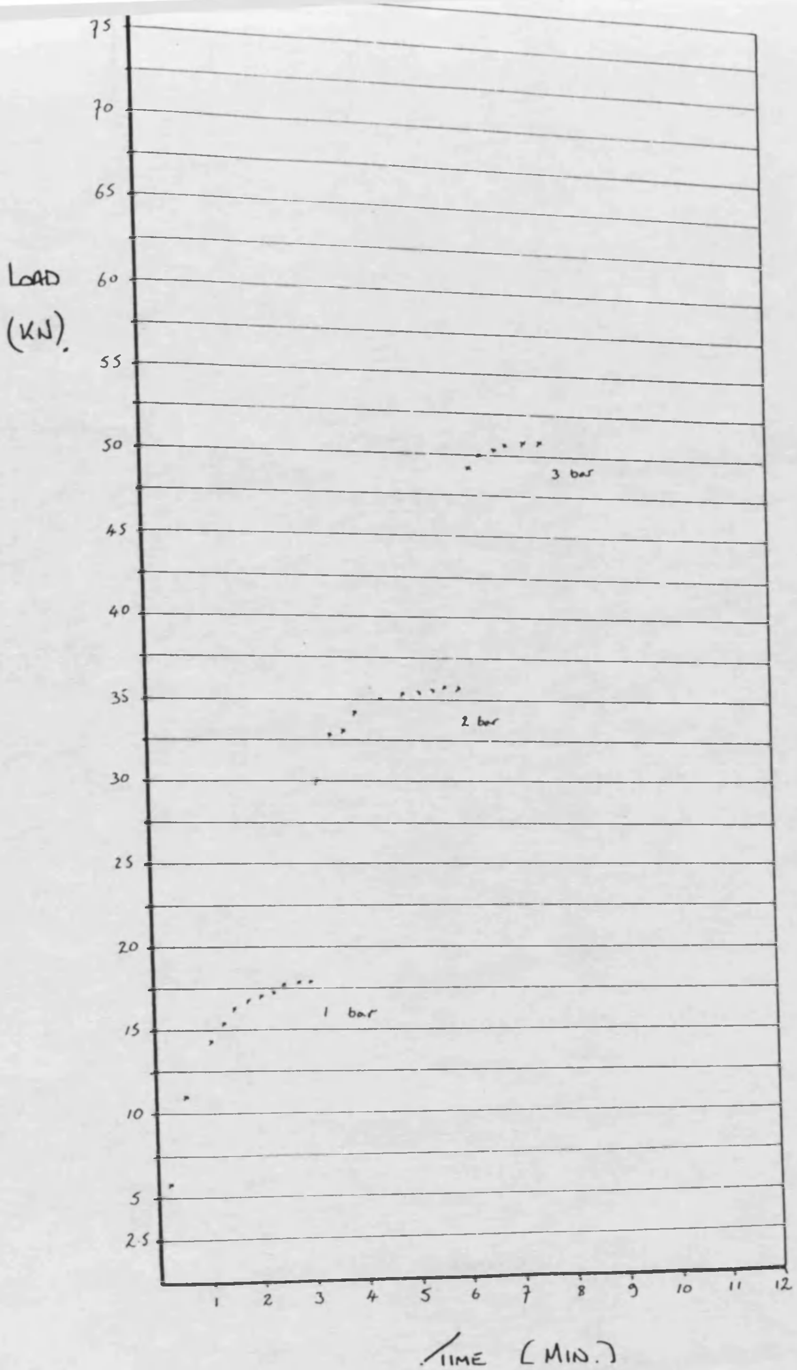
TEST 3


Proving Ring Div.
5 bar
4 bar
3 bar
2 bar
1 bar 'Not used'
Time (Min.)

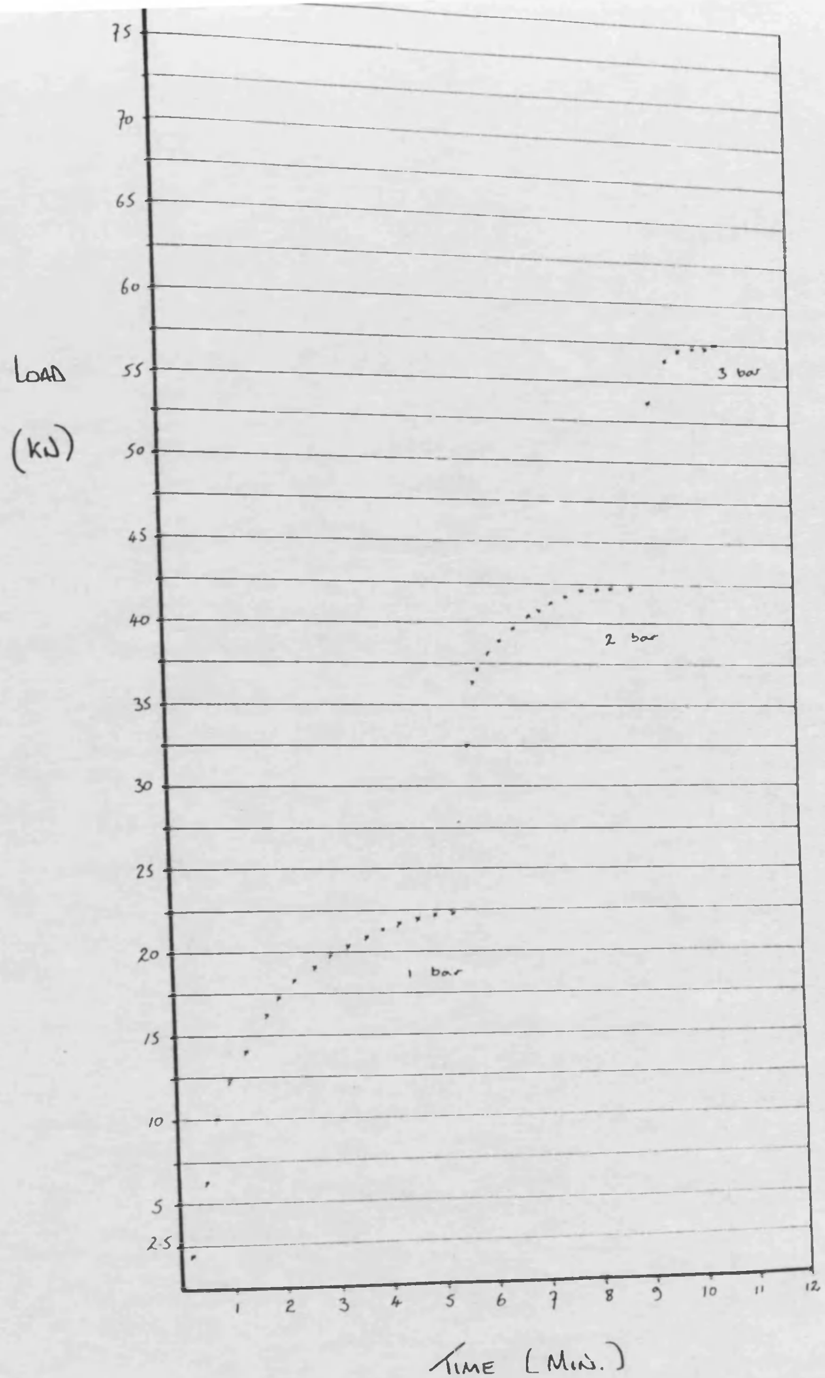

Proving Ring Div.
5 bar
4 bar
3 bar
2 bar
Time (Min.)


5 bar
4 bar
3 bar
2 bar
TIME (MIN.)

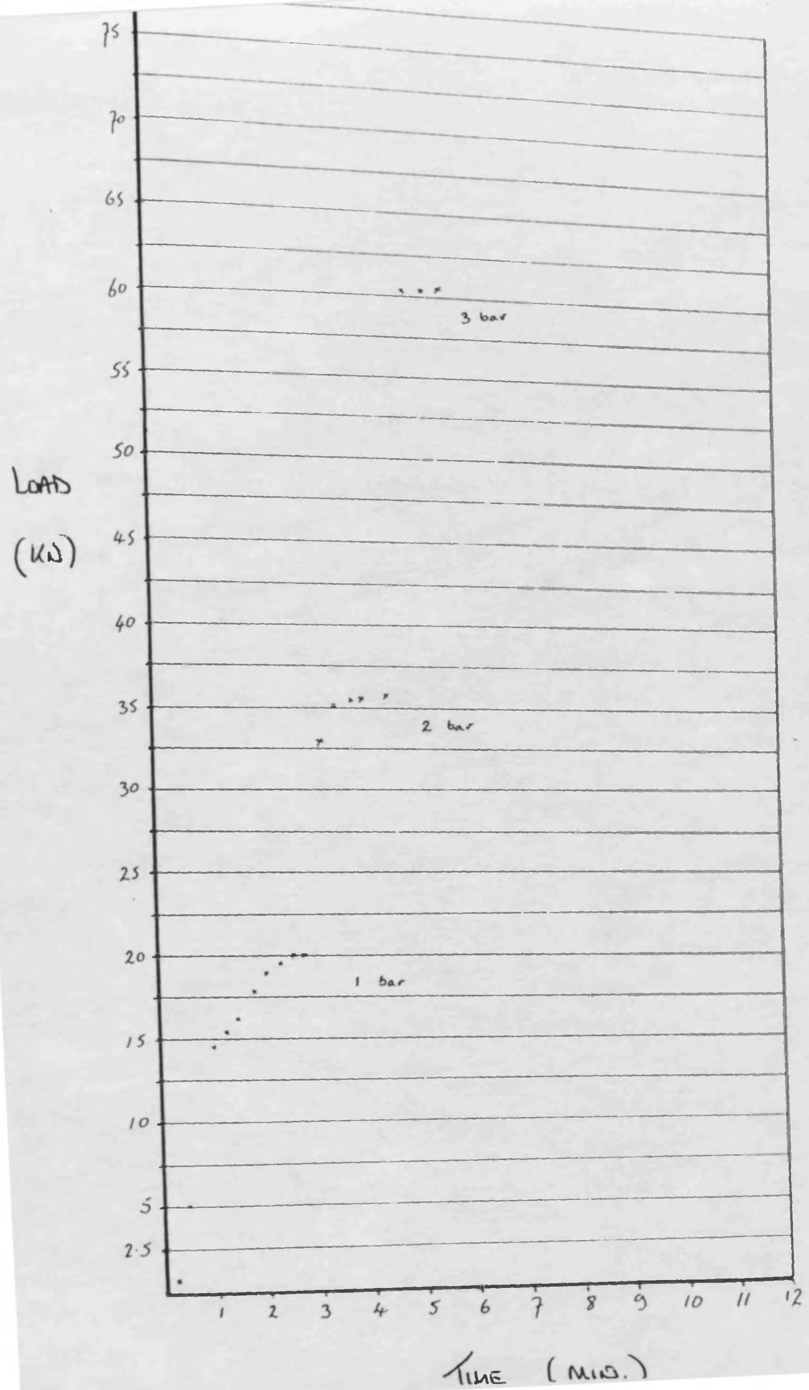

5 bar
4 bar
3 bar
2 bar
1 bar
TIME (MIN.)



LOAD
(KN)
75
70
65
60
55
50
45
40
35
30
25
20
15
10
5
2.5
3 bar
2 bar
1 bar
1
2
3
4
5
6
7
8
9
10
11
12
TIME (MIN.)



LOAD
(KN)
75
70
65
60
55
50
45
40
35
30
25
20
15
10
5
2.5
3 bar
2 bar
1 bar
1
2
3
4
5
6
7
8
9
10
11
12
TIME (MIN.)


LOAD
(KN)
75
70
65
60
55
50
45
40
35
30
25
20
15
10
5
2.5
3 bar
2 bar
1 bar
1
2
3
4
5
6
7
8
9
10
11
12
TIME (MINS.)

Test results for 2nd stage static calibration tests, as detailed in sections 8.3.6, 8.3.7 and 8.3.8. Sample sizes used - predominately 38mm and 100mm, only a few 254mm.

Includes;

1. Summary table.

2. Raw data plots using area correction method. Both multi-stage and single stage tests performed.

3. Derived Mohr circle diagrams for multi stage tests.

SUMMARY TABLE OF 2nd STAGE CALIBRATION TESTS

test no.	sample dia. mm	material	Test type	mass g	voids ratio	Rel. den. %	σ_3 kN/m^2	σ_1 kN/m^2	ϕ (°)
1	100	Cal. Sand	multi stage	2247	0.585	80	100 200 300 400	471 879 1131 1403	41 39 36 34
2	100	Cal. Sand	multi stage	2247	0.585	80	200 300 400 500	850 1214 1562 1878	38 37 36 35
3	100	Cal. Sand	single	2247	0.585	80	200	844	38
4	100	Cal. Sand	multi stage	2247	0.585	80	200 300 400	835 1173 1473	38 36 35
5	100	Cal. Sand	multi stage	2066	0.724	13	200 300 400	771 1087 1387	36 35 34
6	100	Cal. Sand	single	2086	0.707	21	200	724	35
7	100	Cal. Sand	multi stage	2209	0.612	67	200 300 400	777 1141 1479	36 36 35
8	100	Cal. Sand	multi stage	2140	0.664	42	200 300 400	720 1125 1447	34 35 35
9	100	Cal. Sand	multi stage	2086	0.707	21	200 300 400	727 1052 1346	35 34 33
10	100	Cal. Sand	single	2209	0.612	67	400	1605	37

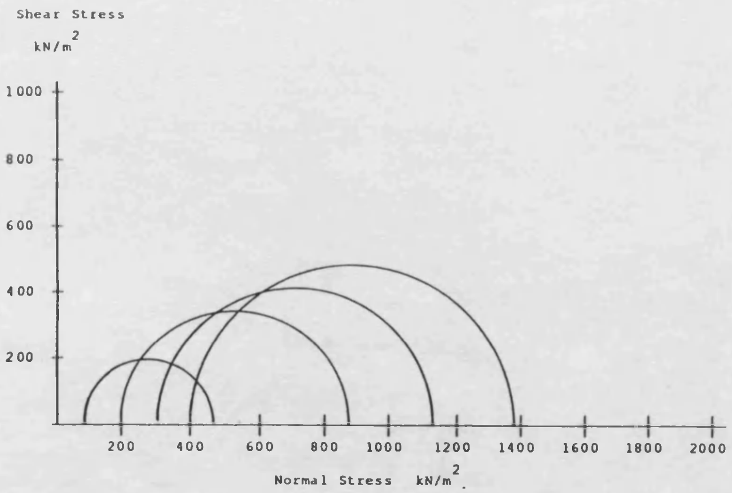
test no.	sample dia. mm	material	Test type	mass g	voids ratio	Rel. den. %	σ_3 kN/m^2	σ_1 kN/m^2	ϕ (°)
11	100	Cal. Sand	single	2209	0.612	67	400	1447	35
12	38	Cal. Sand	multi stage	103.5	0.612	67	200 300	788 1132	37 36
13	38	Cal. Sand	multi stage	103.5	0.612	67	200 300	764 1094	36 35
14	38	Cal. Sand	multi stage	100	0.668	40	200 300	913 1117	40 35
15	38	Cal. Sand	multi stage	97.2	0.716	17	200 300	865 1084	39 35
16	38	Cal. Sand	single	100	0.668	40	400	1499	35
17	100	Type (2) 1 - 2mm grading	single	2068	0.744	80	300	1442	41
18	38	ditto	single	96.86	0.744	80	200	1027	42
19	38	ditto	single	92.75	0.821	50	200	1074	43
20	38	ditto	multi stage	87.3	0.934	20	200 300	1133 1399	44 40
21	100	ditto	multi stage	2068	0.744	80	200 300	1142 1496	45 42
22	38	ditto	single	96.86	0.744	80	400	1891	41
23	38	ditto	multi stage	87.3	0.934	20	200 300	996 1296	42 39
24	38	ditto	multi stage	96.86	0.744	80	200 300 400	1150 1452 1736	44 41 39
25	38	ditto	multi stage	92.76	0.824	50	200 300 400	1090 1440 1706	44 41 38

test no.	sample dia. mm	material	Test type	mass g	voids ratio	Rel. den. %	σ_3 kN/m^2	σ_1 kN/m^2	ϕ (°)
26	100	Type (2) 1 - 2mm grading	multi stage	1980	0.821	50	200 300	1040 1357	43 40
27	100	ditto	multi stage	1895	0.903	30	200 300	1072 1394	43 40
28	254	ditto	single	28.3kg	0.62	63	200	879	39

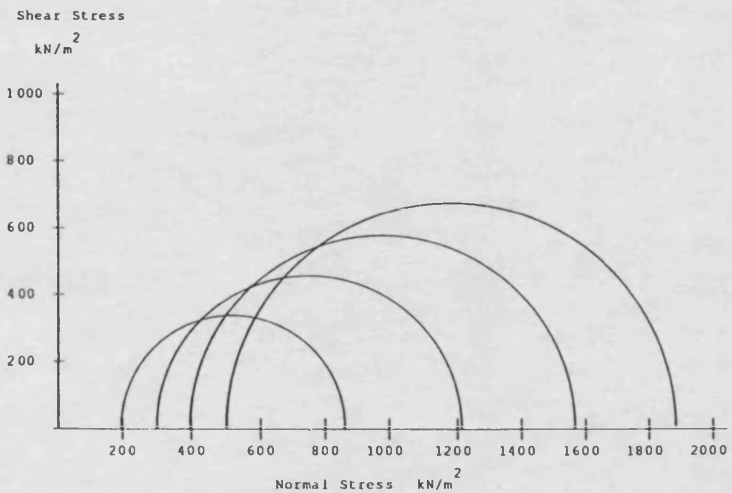
sample volume for 100mm samples = 1352 cc

sample volume for 38mm samples = 63.33 cc

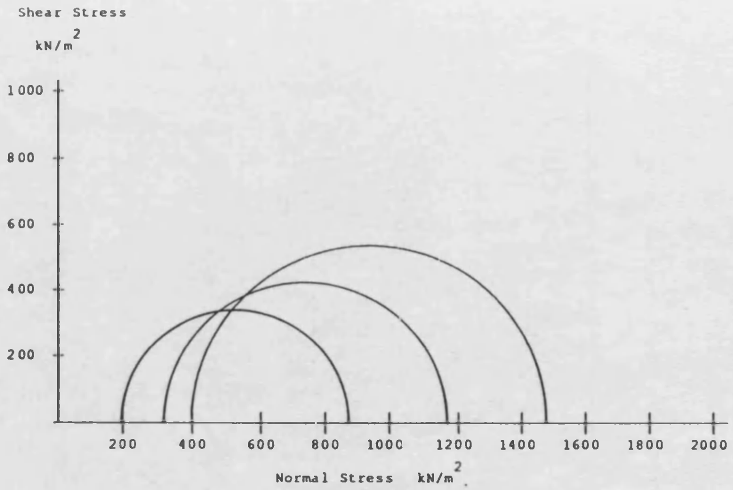
Tests on 38mm samples were carried out with drain line closed during axial load application, but the vacuum had been released. If this had any effect it would be to increase the apparent strength of the samples, as air would not be able to escape giving rise to an internal pressure. However, air does compress, still allowing sample compression.



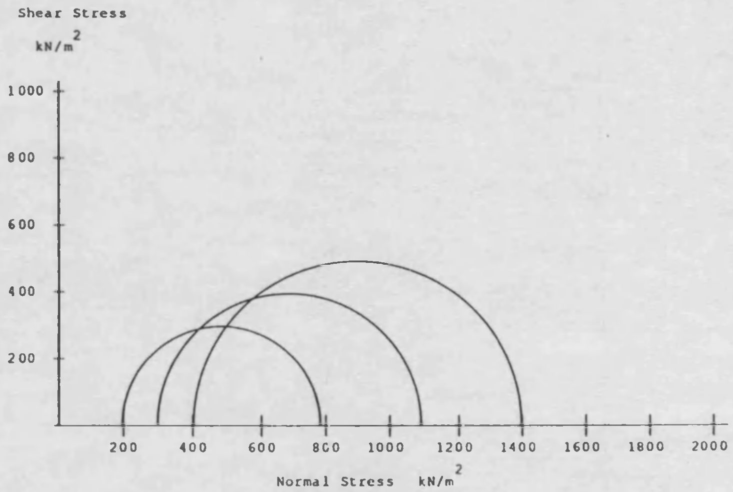
Mohrs circle plot for Test No. 1



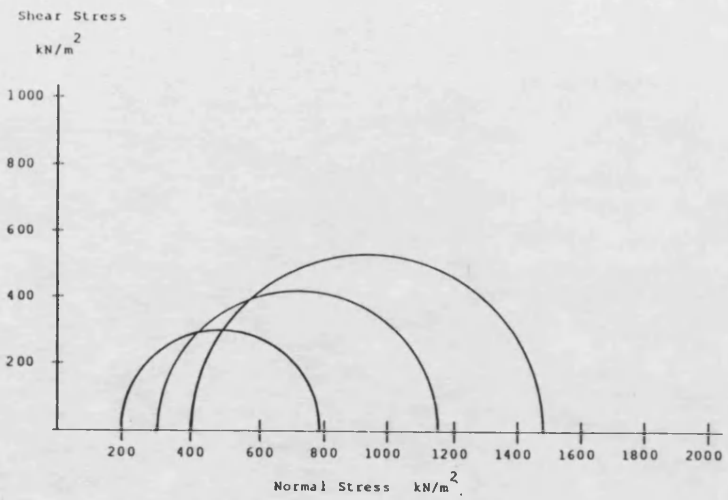
Mohrs circle plot for Test No. 2



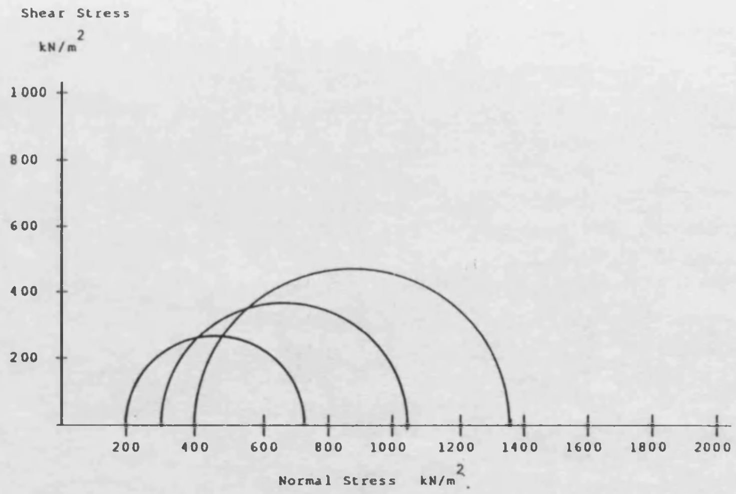
Mohrs circle plot for Test No. 4



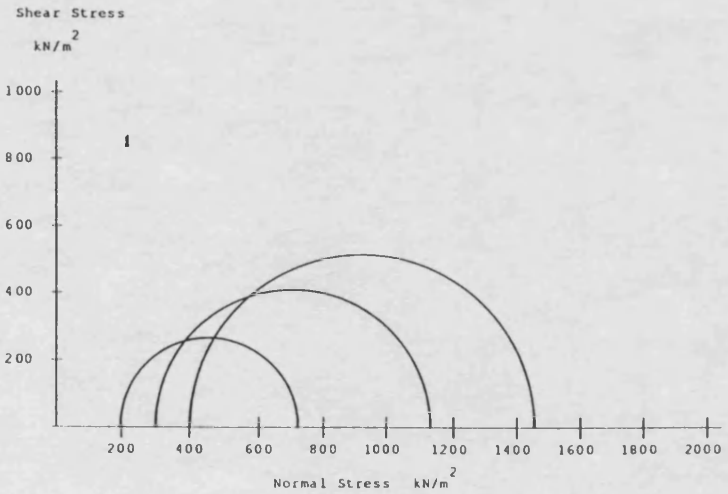
Mohrs circle plot for Test No. 5



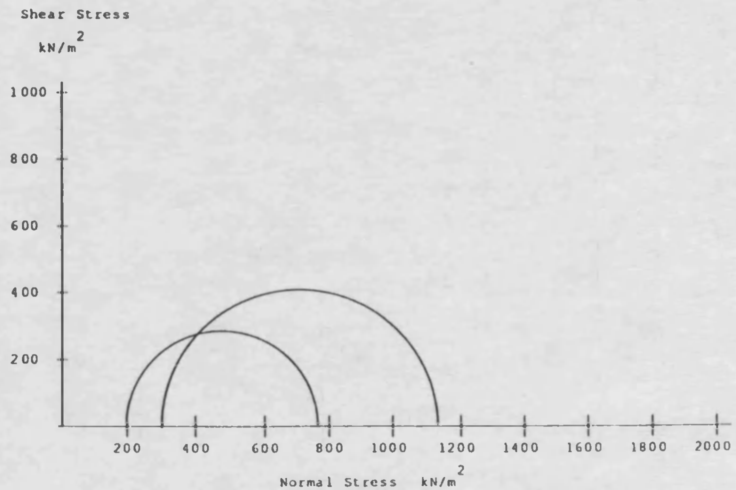
Mohrs circle plot for Test No. 7



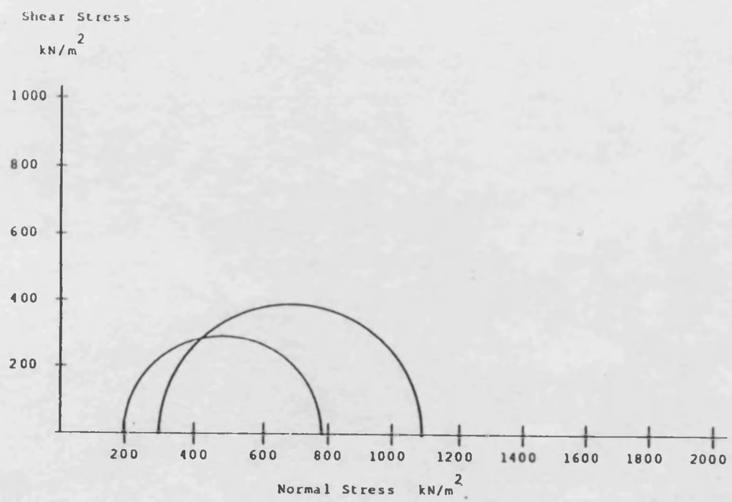
Mohrs circle plot for Test No. 9



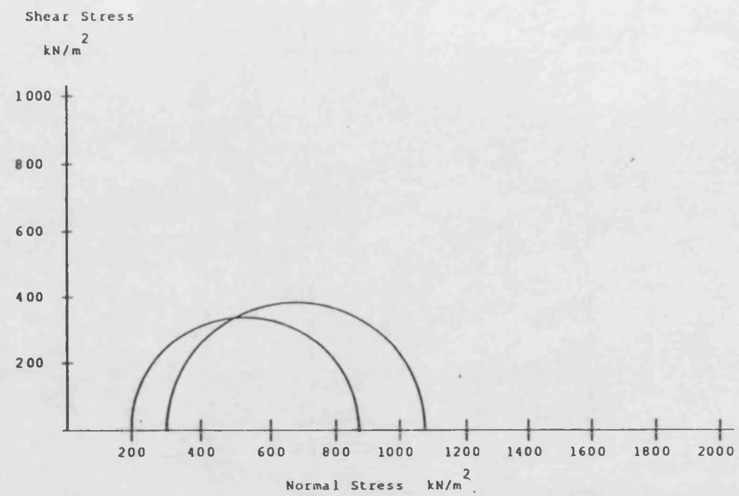
Mohrs circle plot for Test No. 8



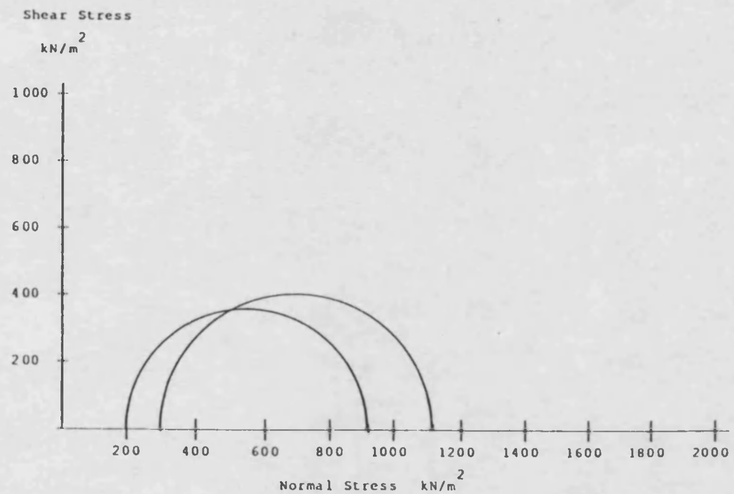
Mohrs circle plot for Test No. 12



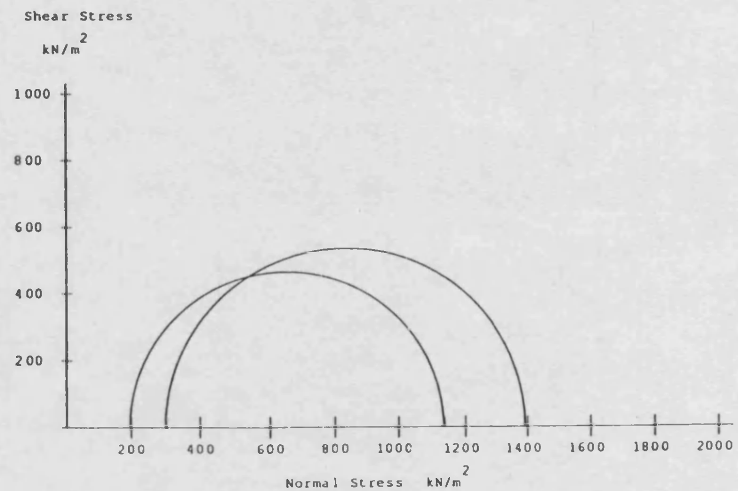
Mohrs circle plot for Test No. 13



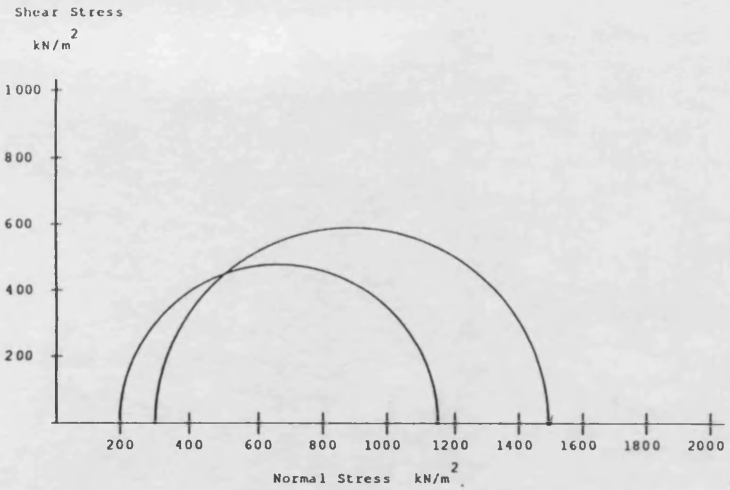
Mohrs circle plot for Test No. 15



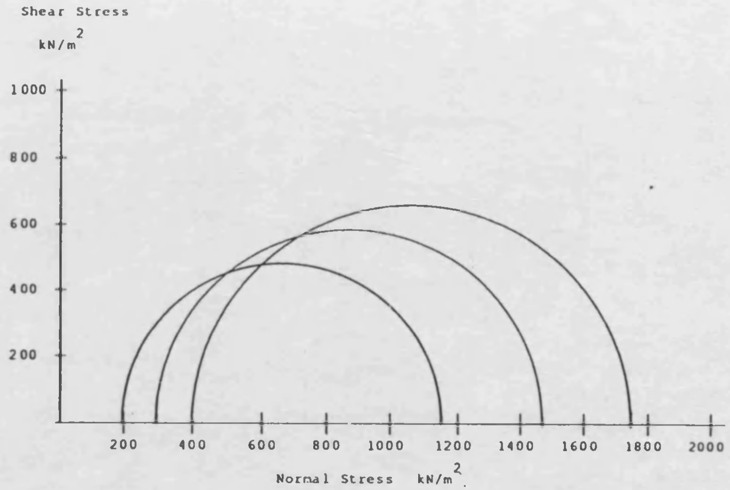
Mohrs circle plot for Test No. 14



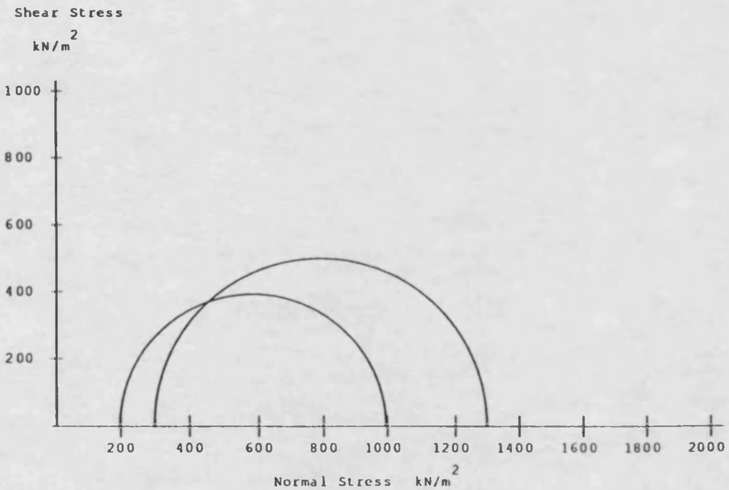
Mohrs circle plot for Test No. 20



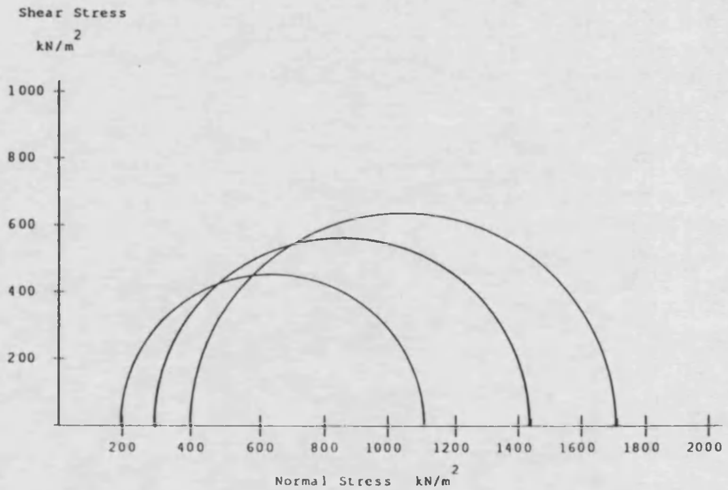
Mohrs circle plot for Test No. 21



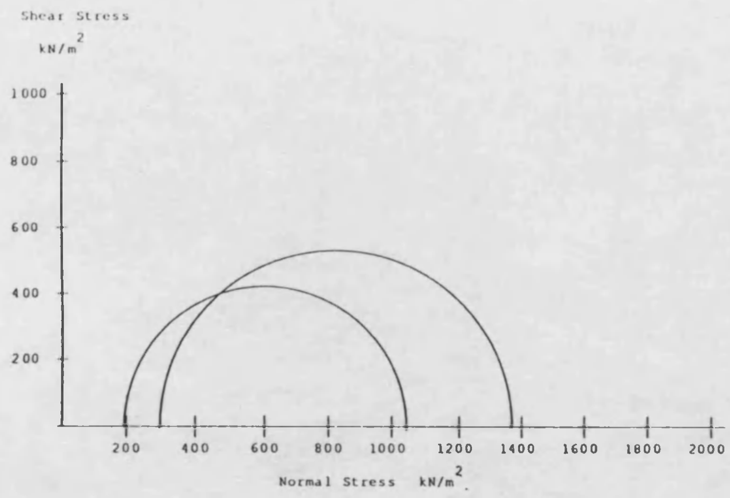
Mohrs circle plot for Test No. 24



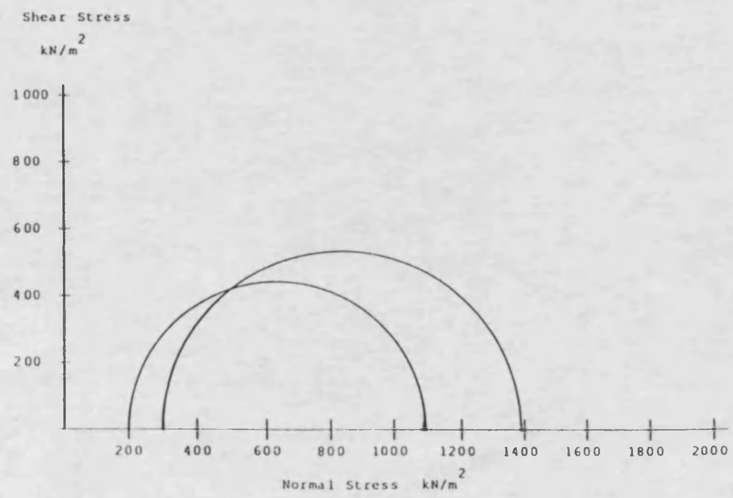
Mohrs circle plot for Test No. 23



Mohrs circle plot for Test No. 25

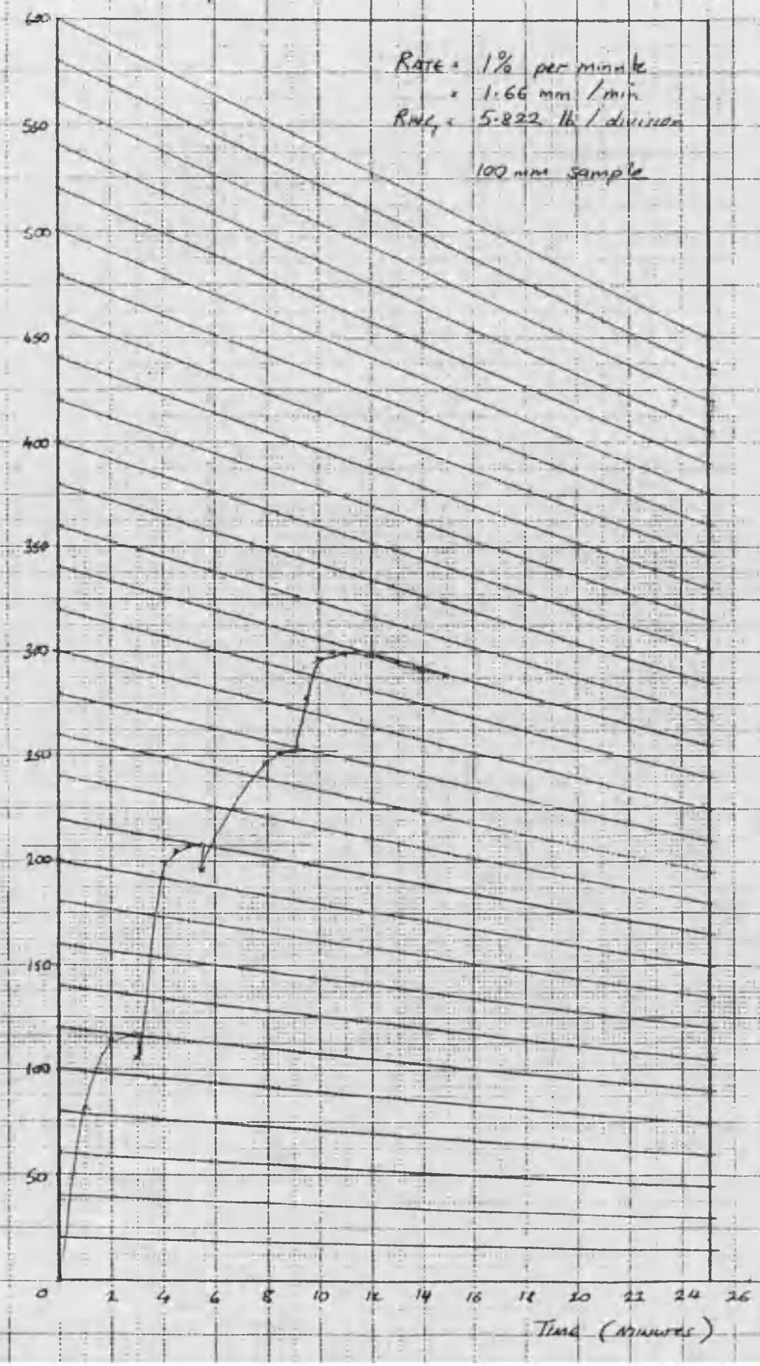


Mohrs circle plot for Test No. 26

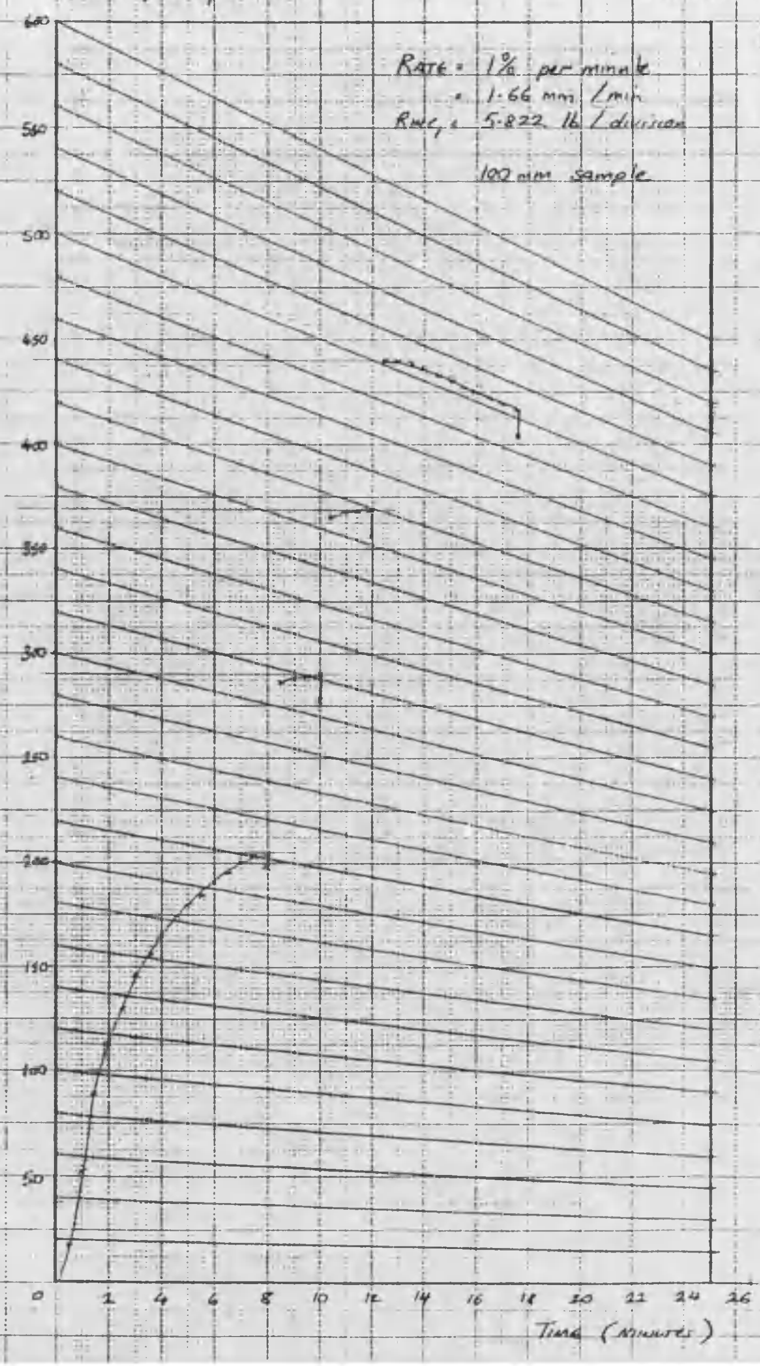


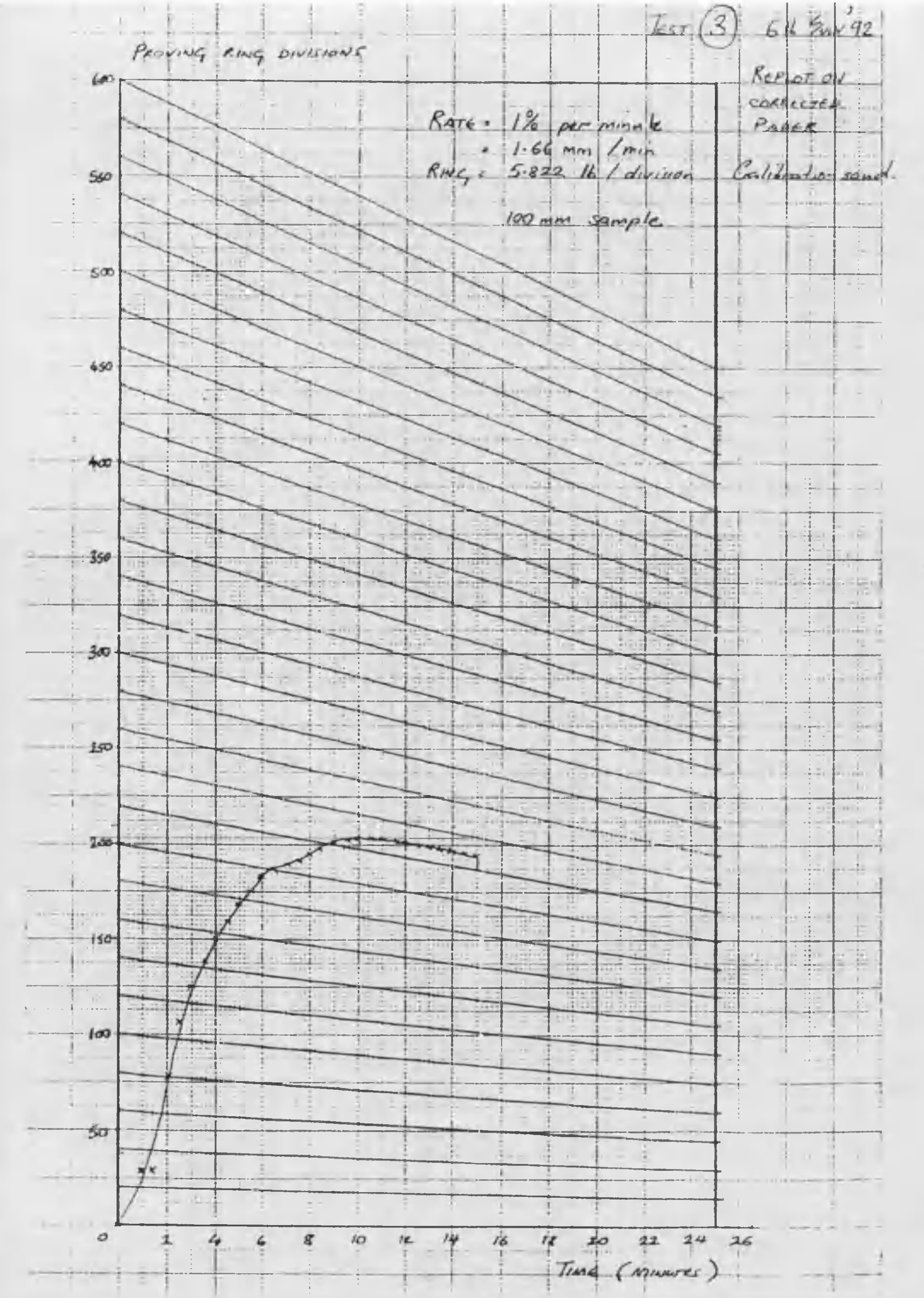
Mohrs circle plot for Test No. 27

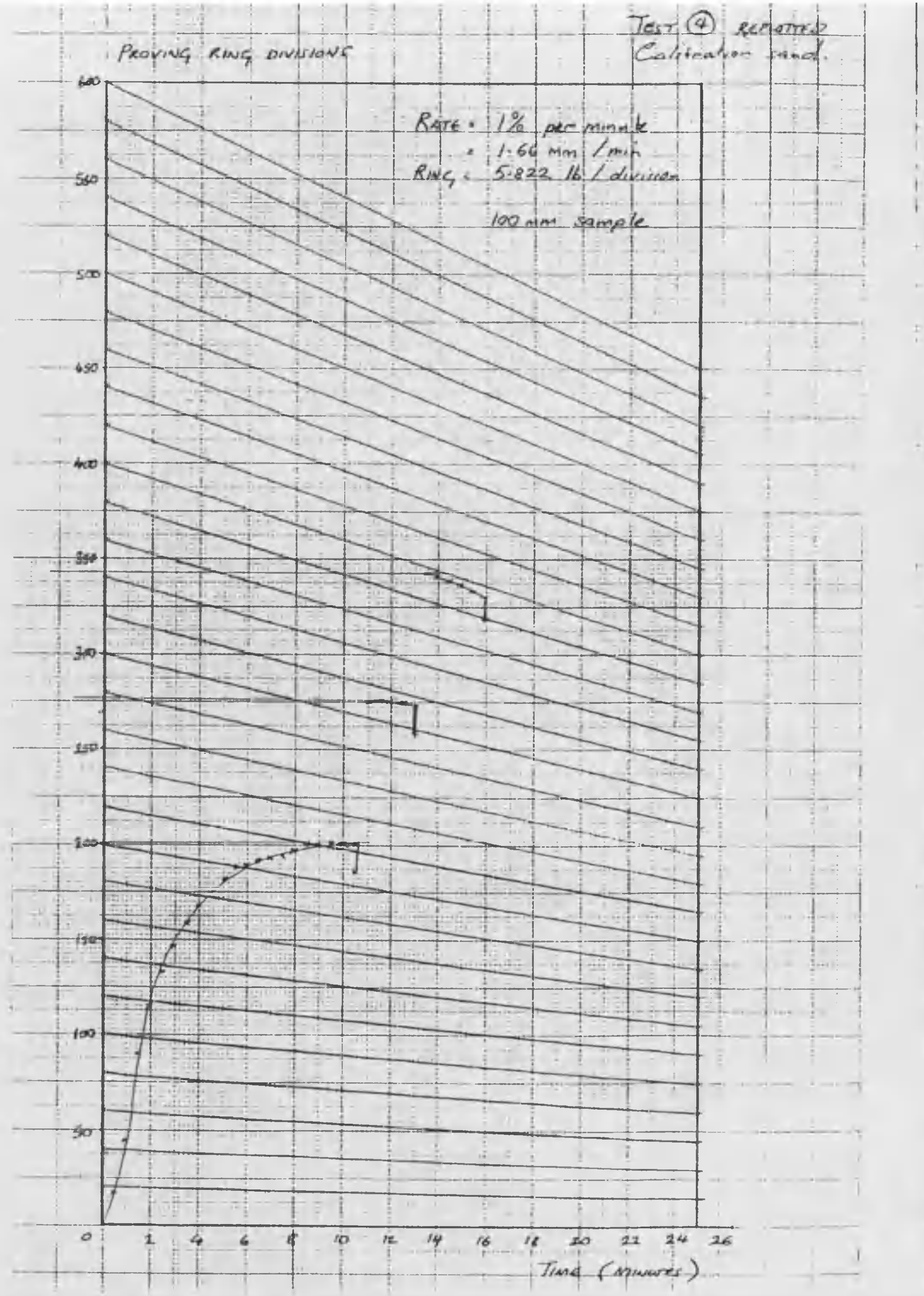
TEST (1) REPLOTTED
Calibration sand

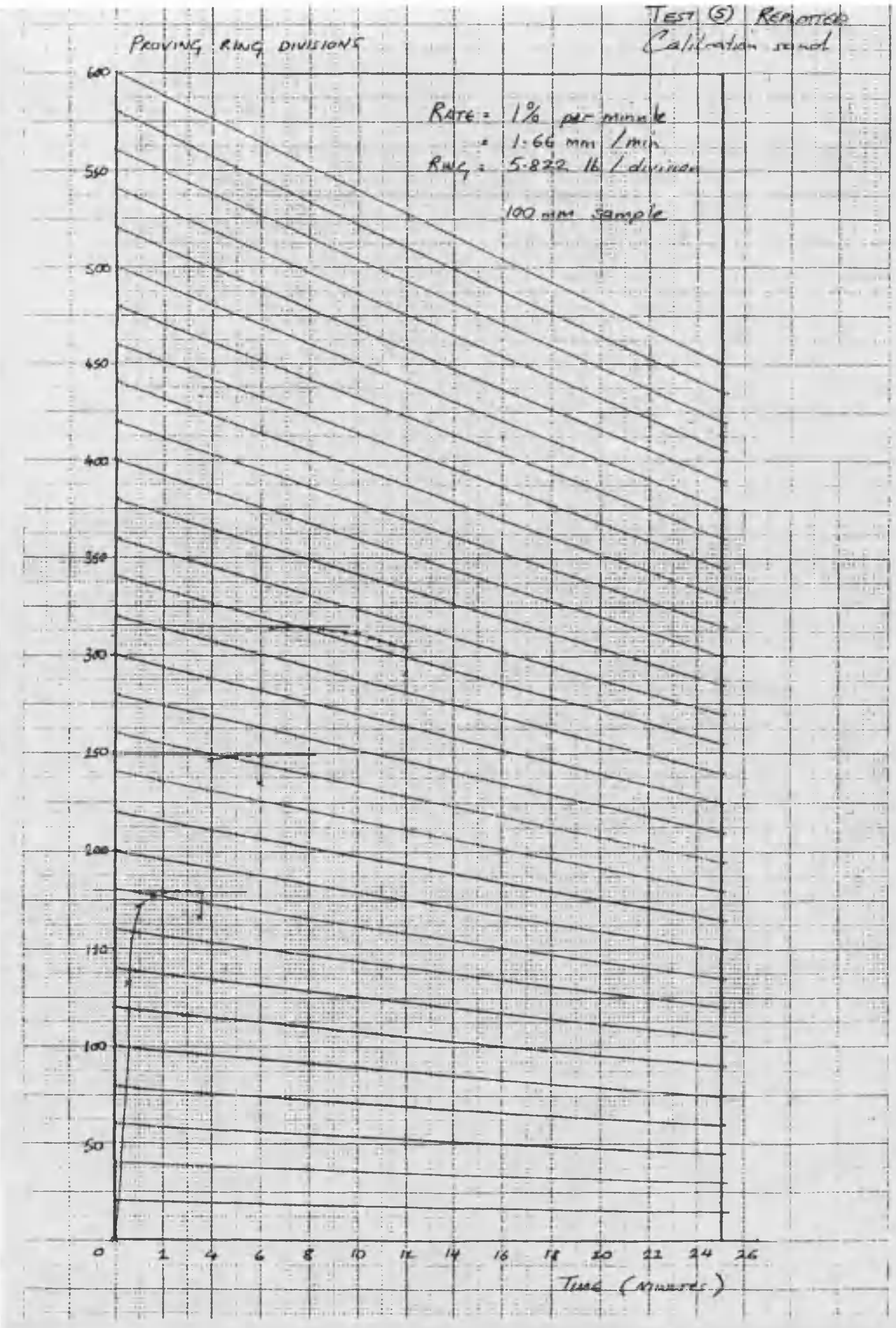


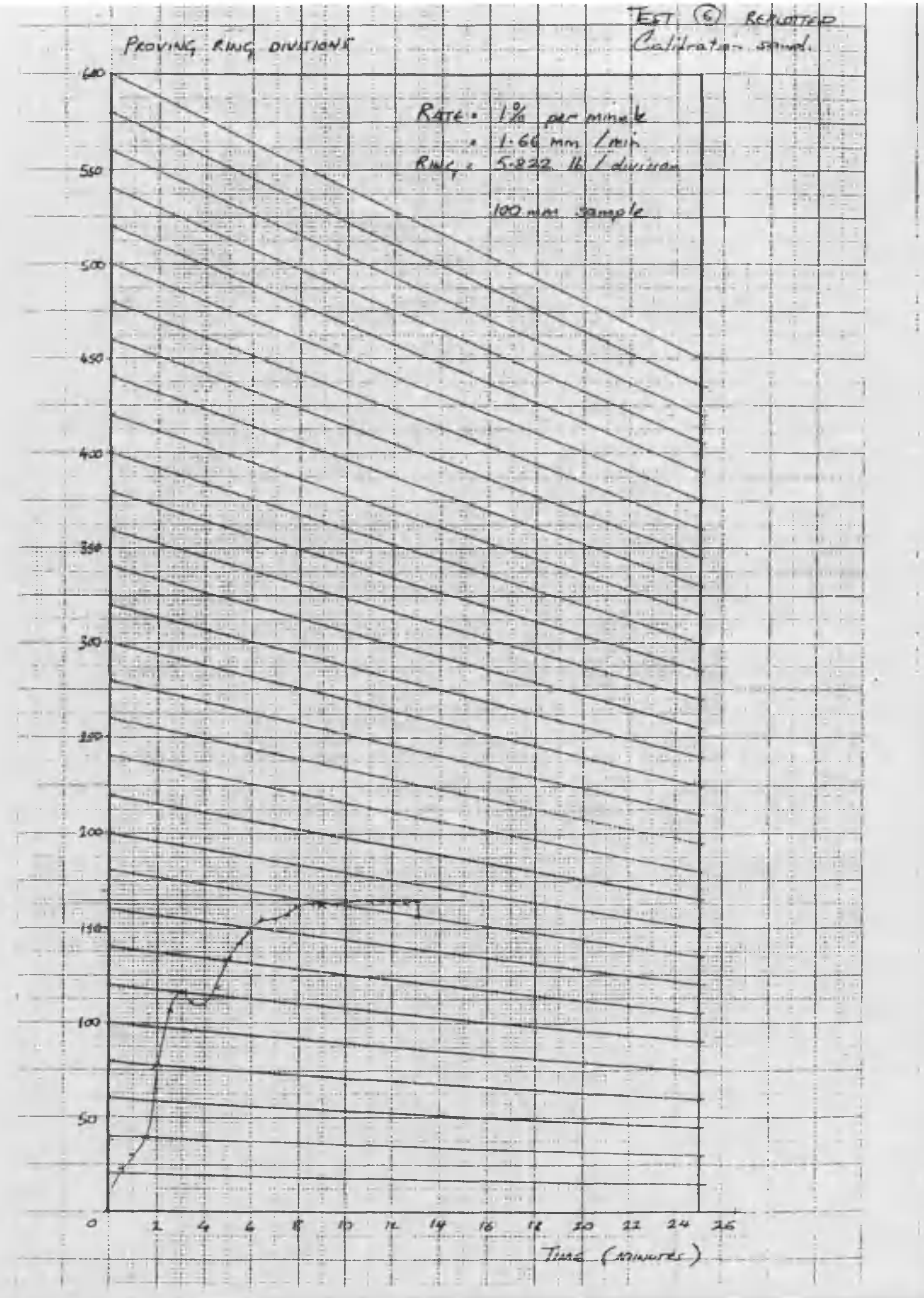
TEST (2) REPLOTTED
Calibration mud

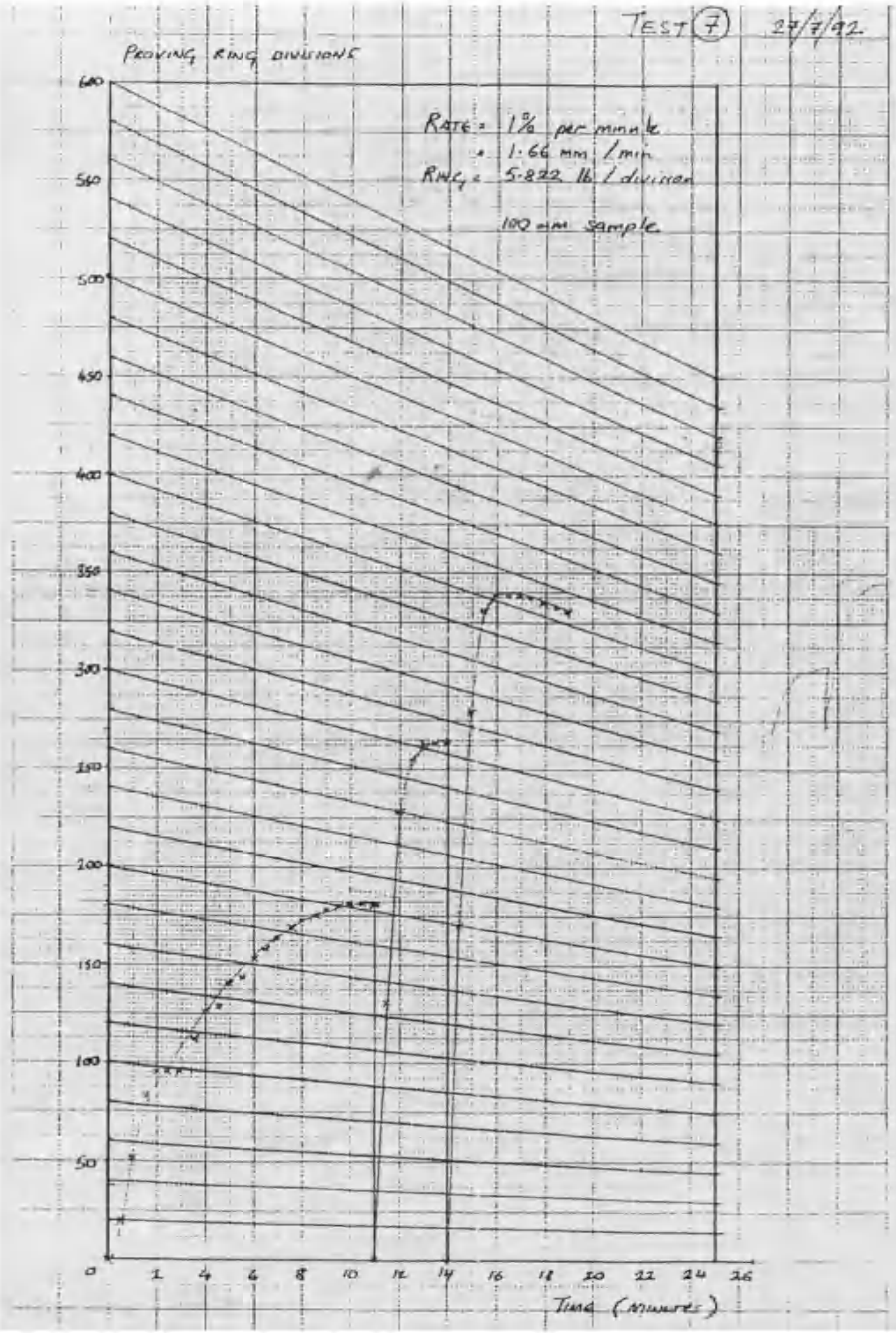



Test (3) 6th Jan '92
Proving ring divisions
Replot on corrected paper
Rate = 1% per minute
= 1.66 mm / min
Ring = 5.822 lb / division
Calibration sand.
100 mm sample
Time (Minutes)

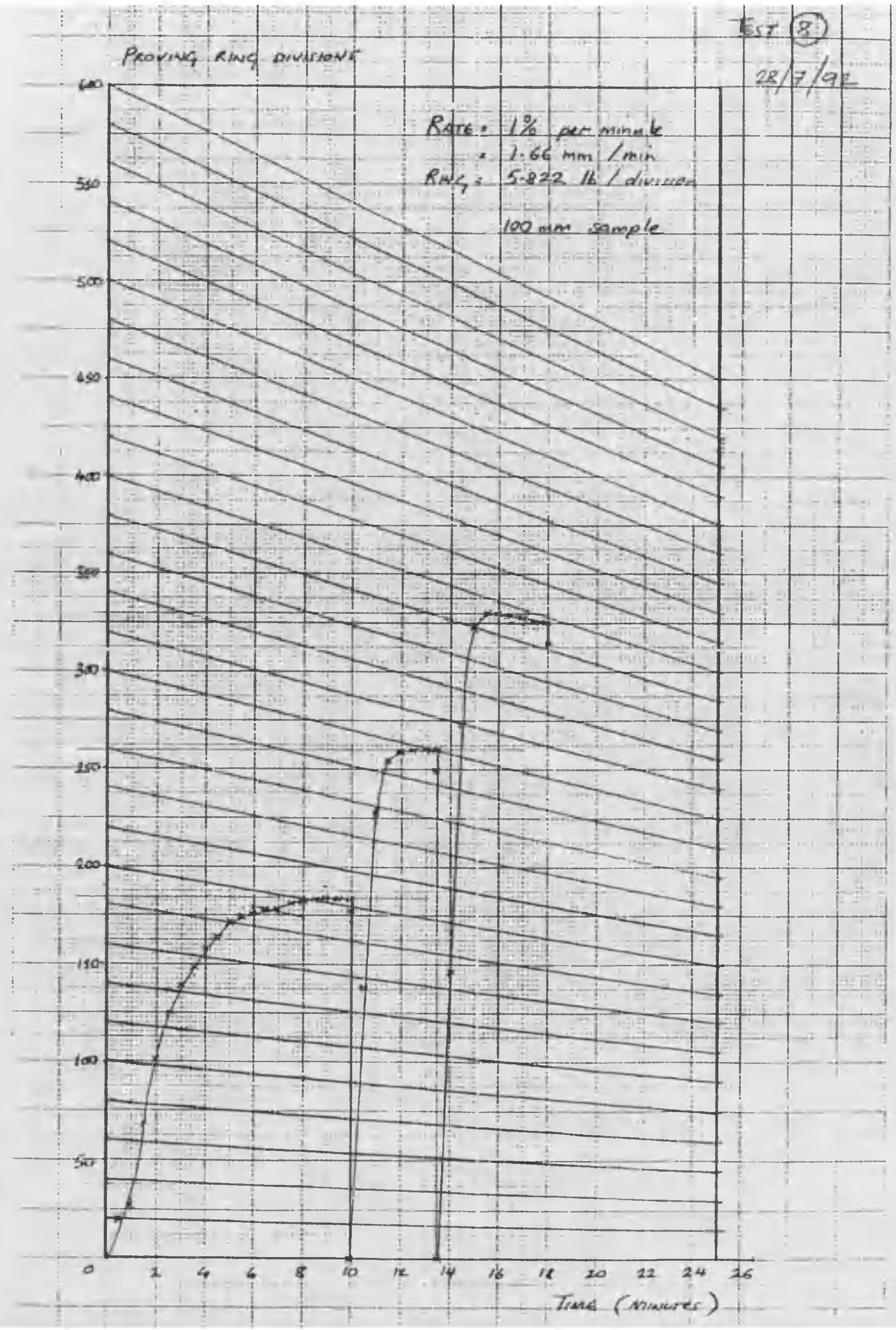

Test (4) Replotted
Calibration sand.
Proving ring divisions
Rate = 1% per minute
= 1.66 mm / min
Ring = 5.822 lb / division
100 mm sample
Time (Minutes)


TEST (5) REPLOTTED
Calibration sand
PROVING RING DIVISIONS
RATE: 1% per minute
: 1·66 mm /min
RING: 5·822 lb / division
100 mm sample
600
550
500
450
400
350
300
250
200
150
100
50
0
2
4
6
8
10
12
14
16
18
20
22
24
26
TIME (MINUTES)

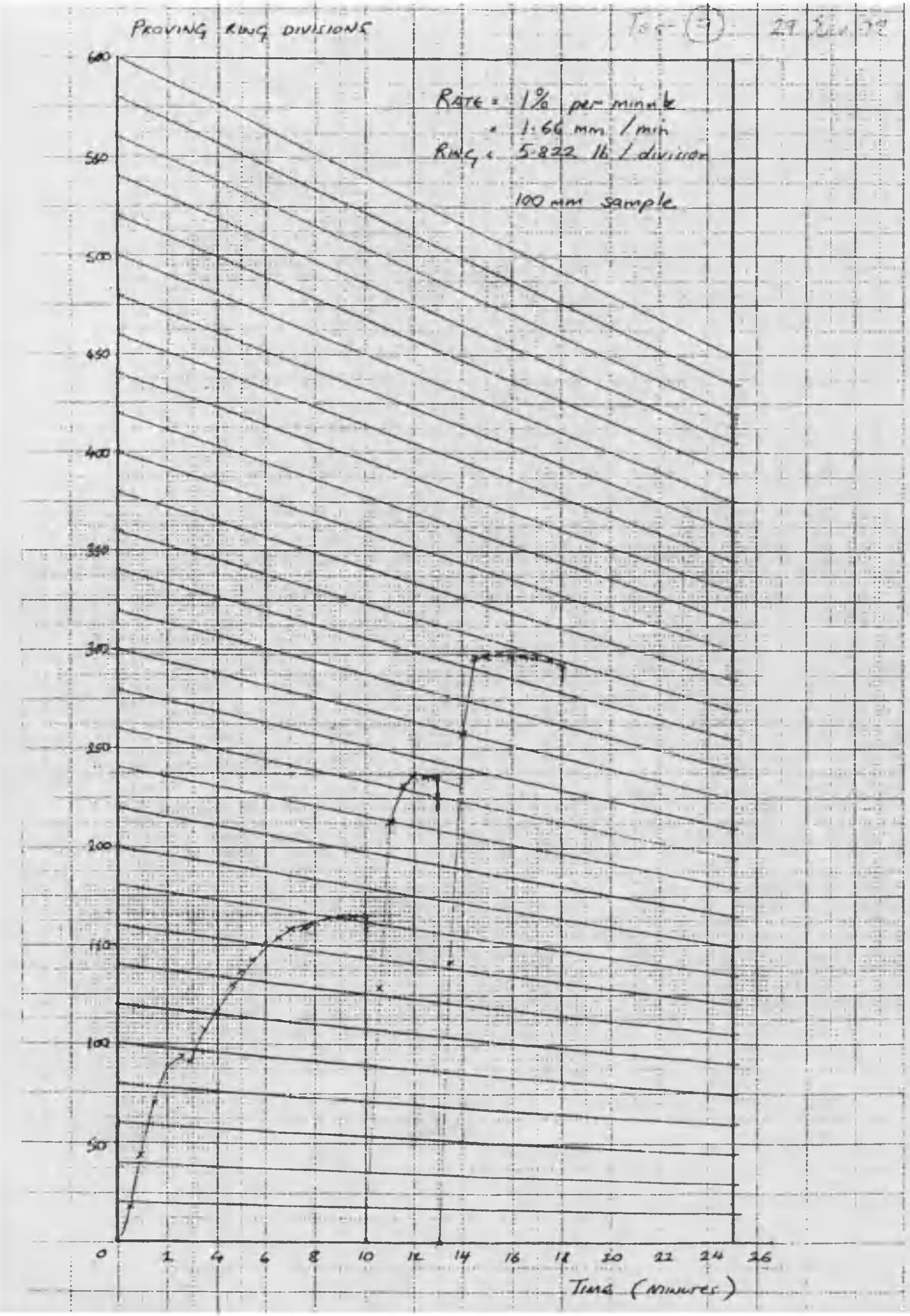

TEST (6) REPLOTTED
Calibration sand.
PROVING RING DIVISIONS
RATE: 1% per minute
: 1·66 mm /min
RING: 5·822 lb / division
100 mm sample
600
550
500
450
400
350
300
250
200
150
100
50
0
2
4
6
8
10
12
14
16
18
20
22
24
26
TIME (MINUTES)

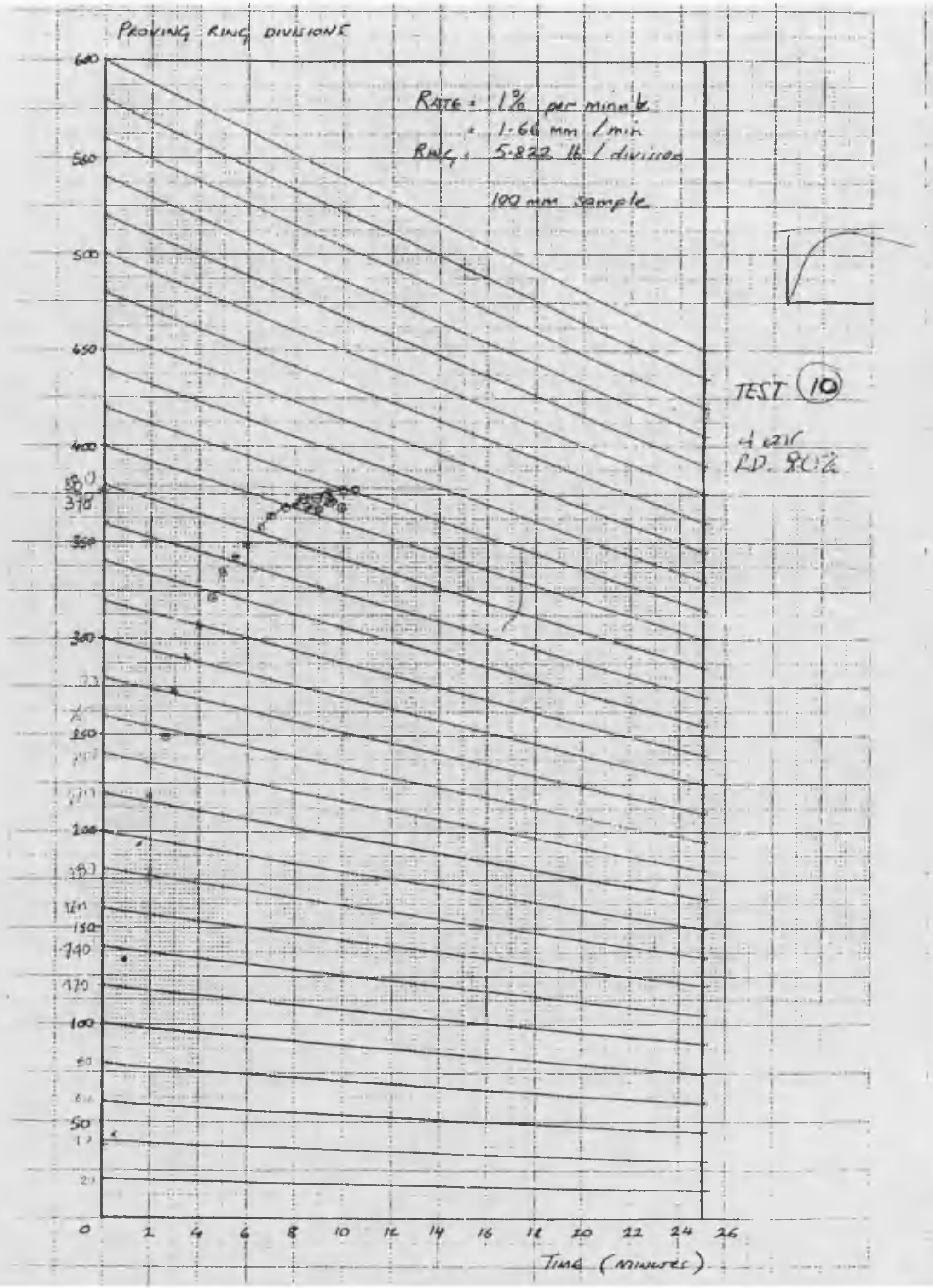


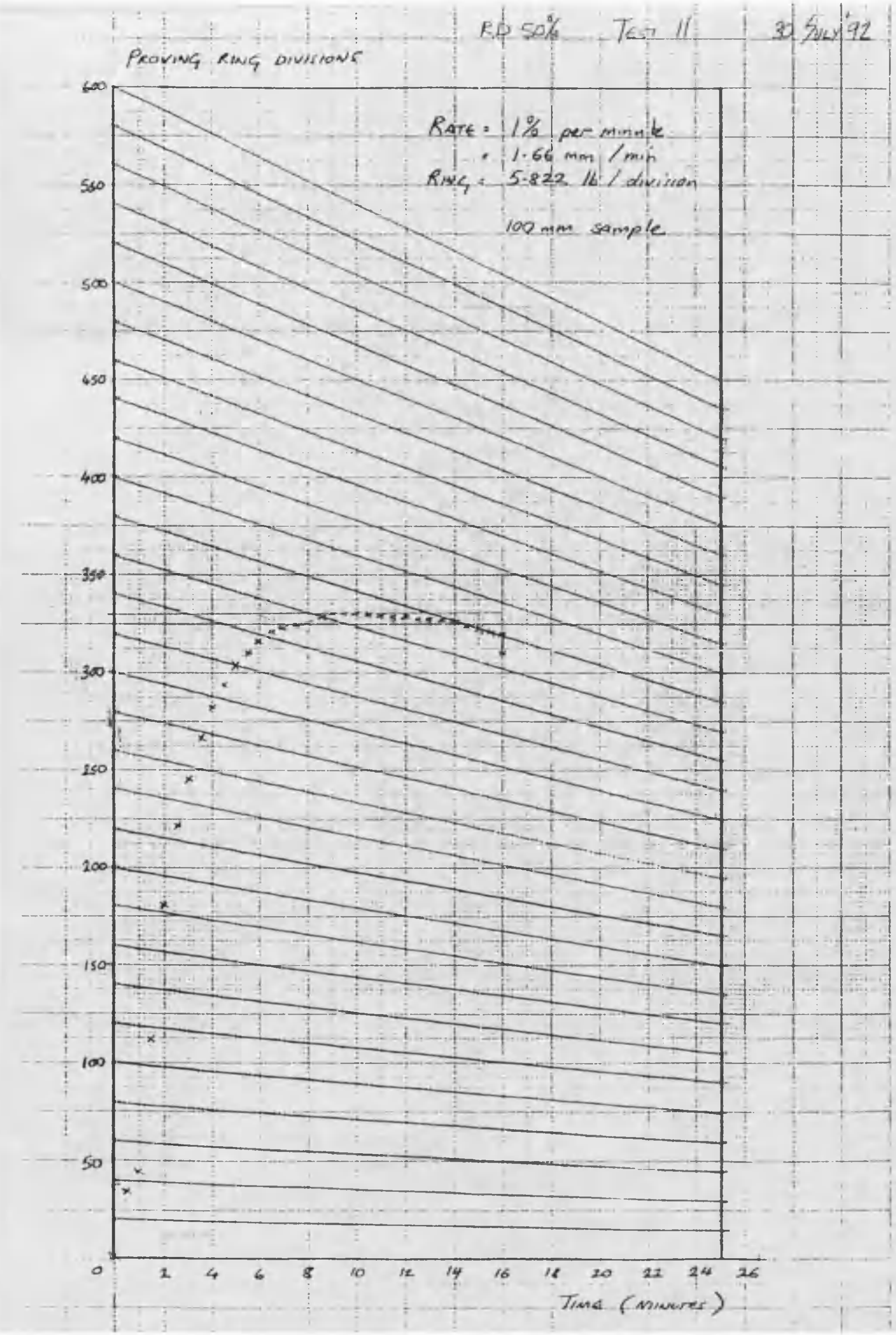
TEST 7 27/7/92.
PROVING RING DIVISIONS
RATE = 1% per minute
= 1.66 mm /min
RING = 5.822 lb / division
100 mm sample
0
50
100
150
200
250
300
350
400
450
500
550
600
0 2 4 6 8 10 12 14 16 18 20 22 24 26
TIME (MINUTES)



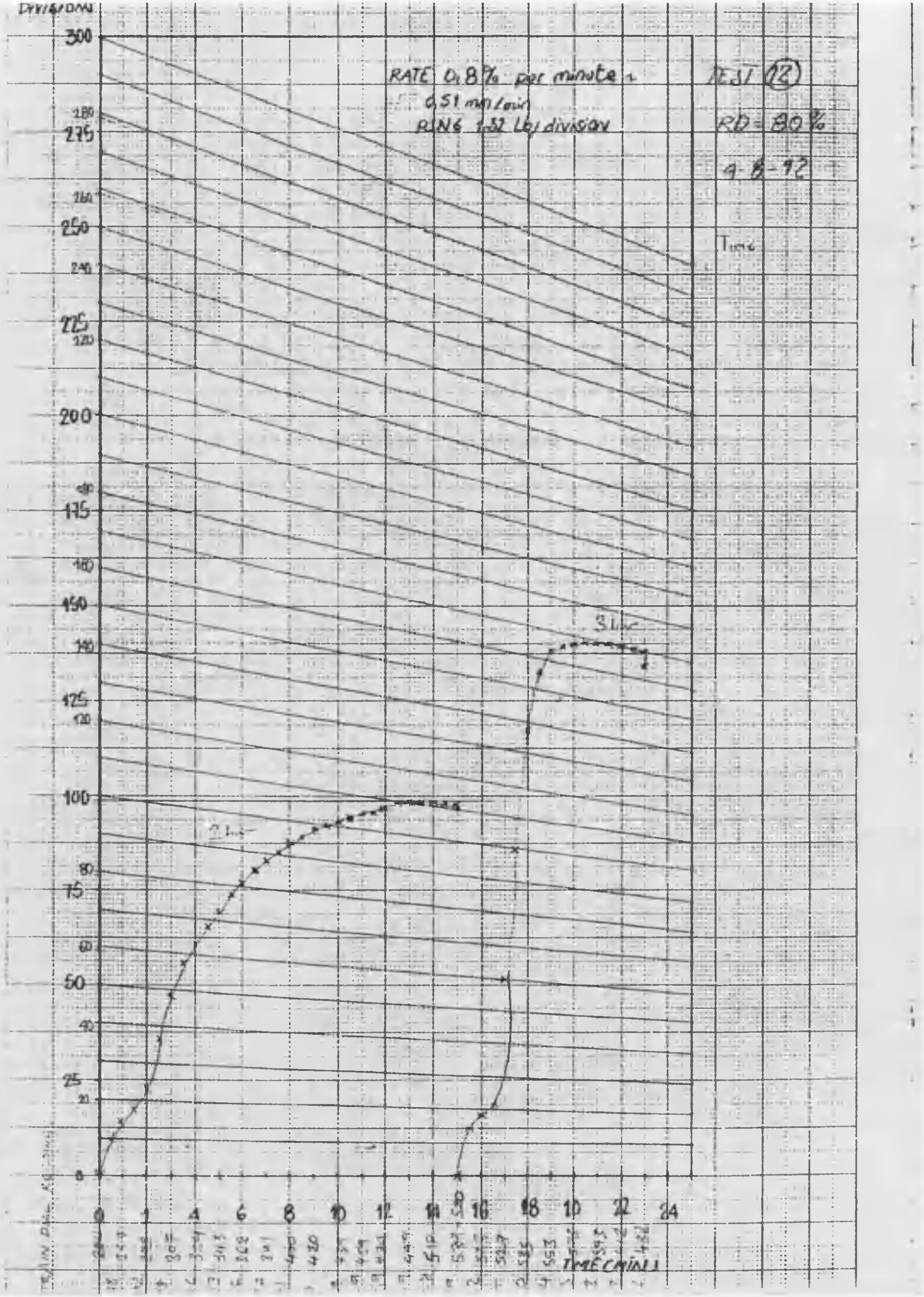
TEST 8 28/7/92
PROVING RING DIVISIONS
RATE = 1% per minute
= 1.66 mm /min
RING = 5.822 lb / division
100 mm sample
0
50
100
150
200
250
300
350
400
450
500
550
600
0 2 4 6 8 10 12 14 16 18 20 22 24 26
TIME (MINUTES)


PROVING RING DIVISIONS
RATE = 1% per minute
= 1.66 mm / min
RING: 5.822 lb / division
100 mm sample
TIME (MINUTES)

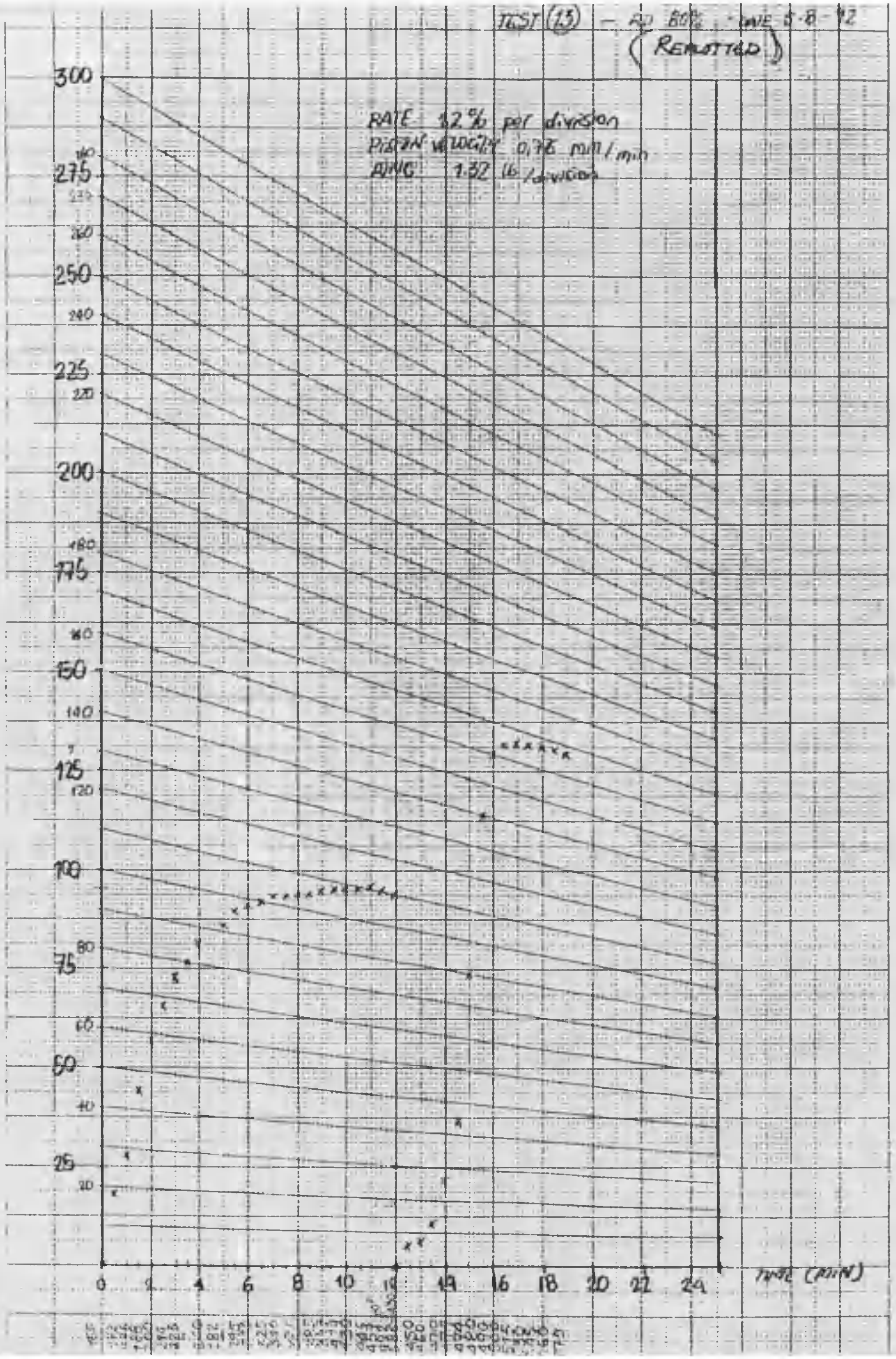

PROVING RING DIVISIONS
RATE = 1% per minute
= 1.66 mm / min
RING: 5.822 lb / division
100 mm sample
TEST 10
RD. 80%
TIME (MINUTES)

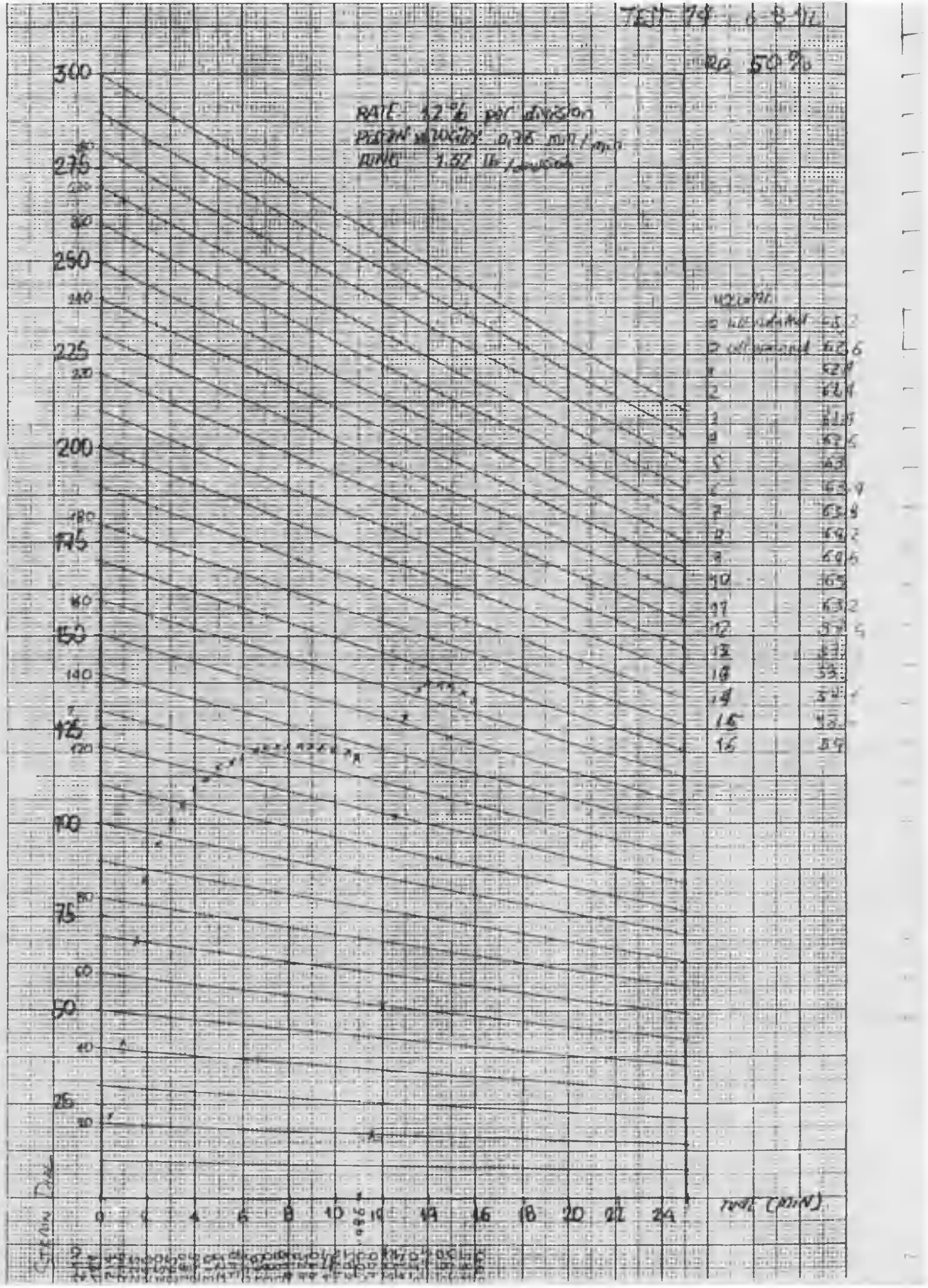


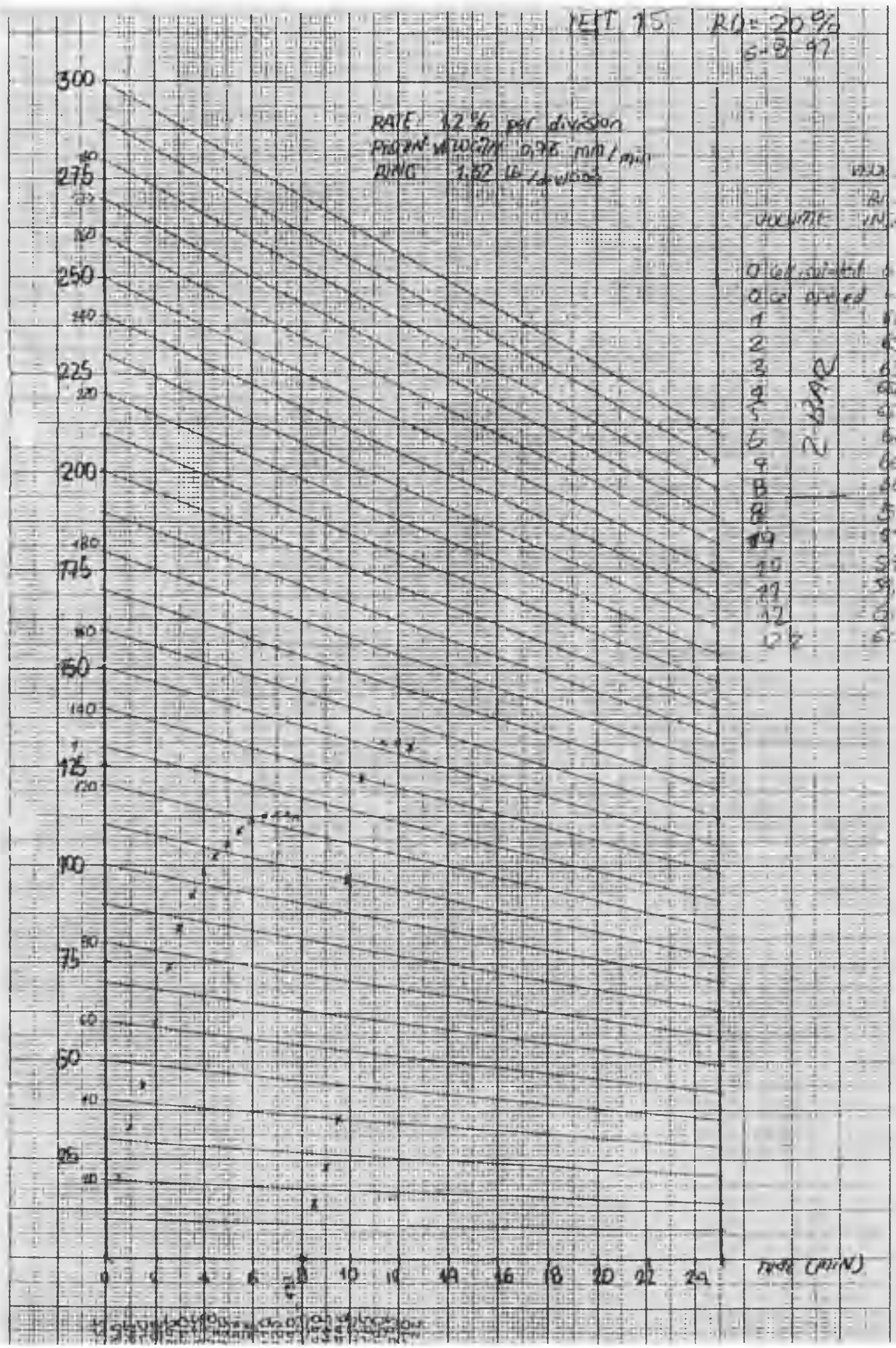
R.D 50%
Test 11
30 July '92
Proving Ring Divisions
Rate = 1% per minute
= 1.66 mm / min
Ring = 5.822 lb / division
100 mm sample
Time (minutes)

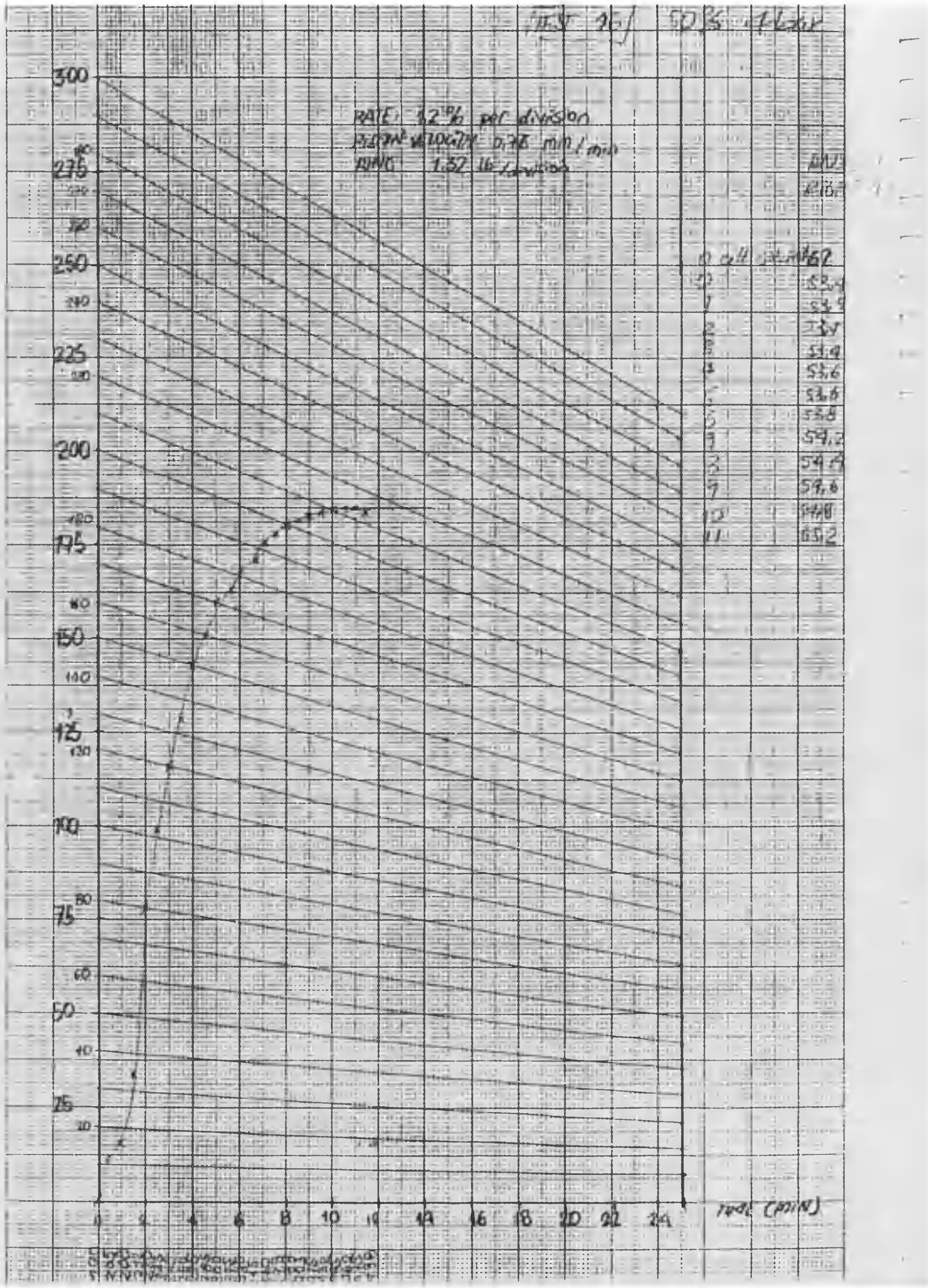


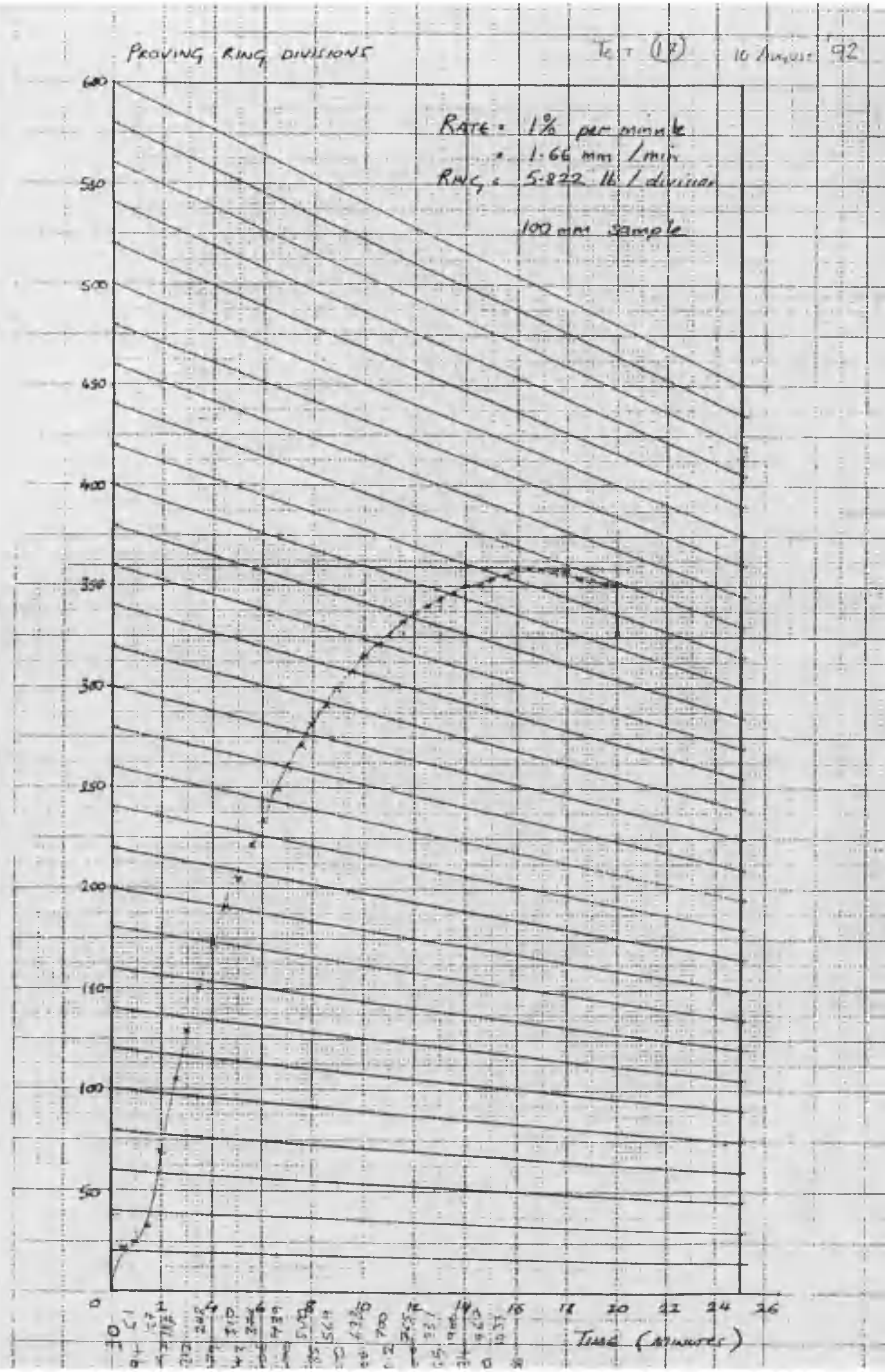
Division
Rate 0.8% per minute =
0.51 mm/min
Ring 1.32 Lb/division
Test 12
RD = 80%
4-8-92
Time
Time (min)


RATE 1.2% per division
RING 1.32 lb/division
TIME (MIN)

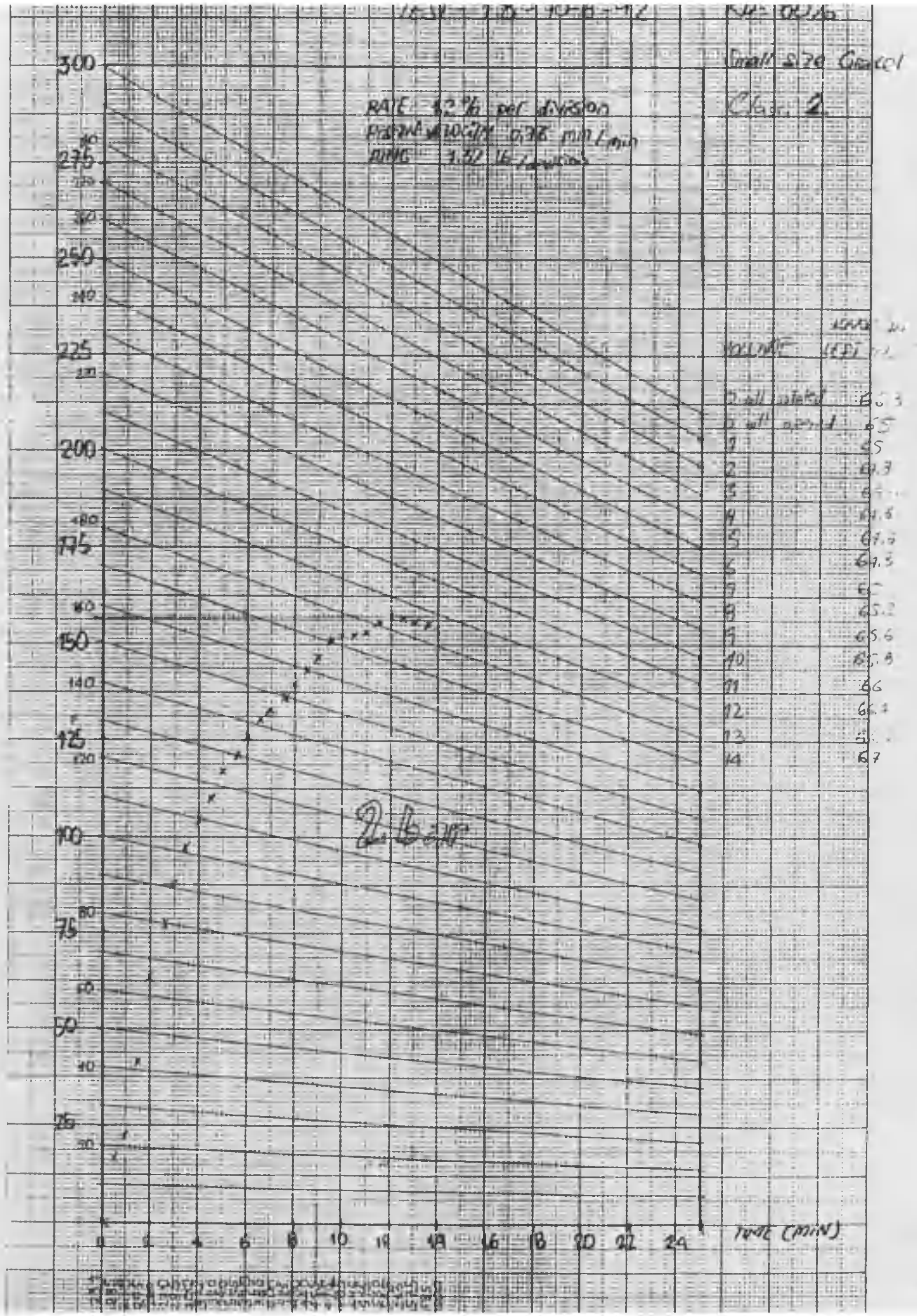

RD 50%
RATE 1.2% per division
RING 1.32 lb/division
TIME (MIN)

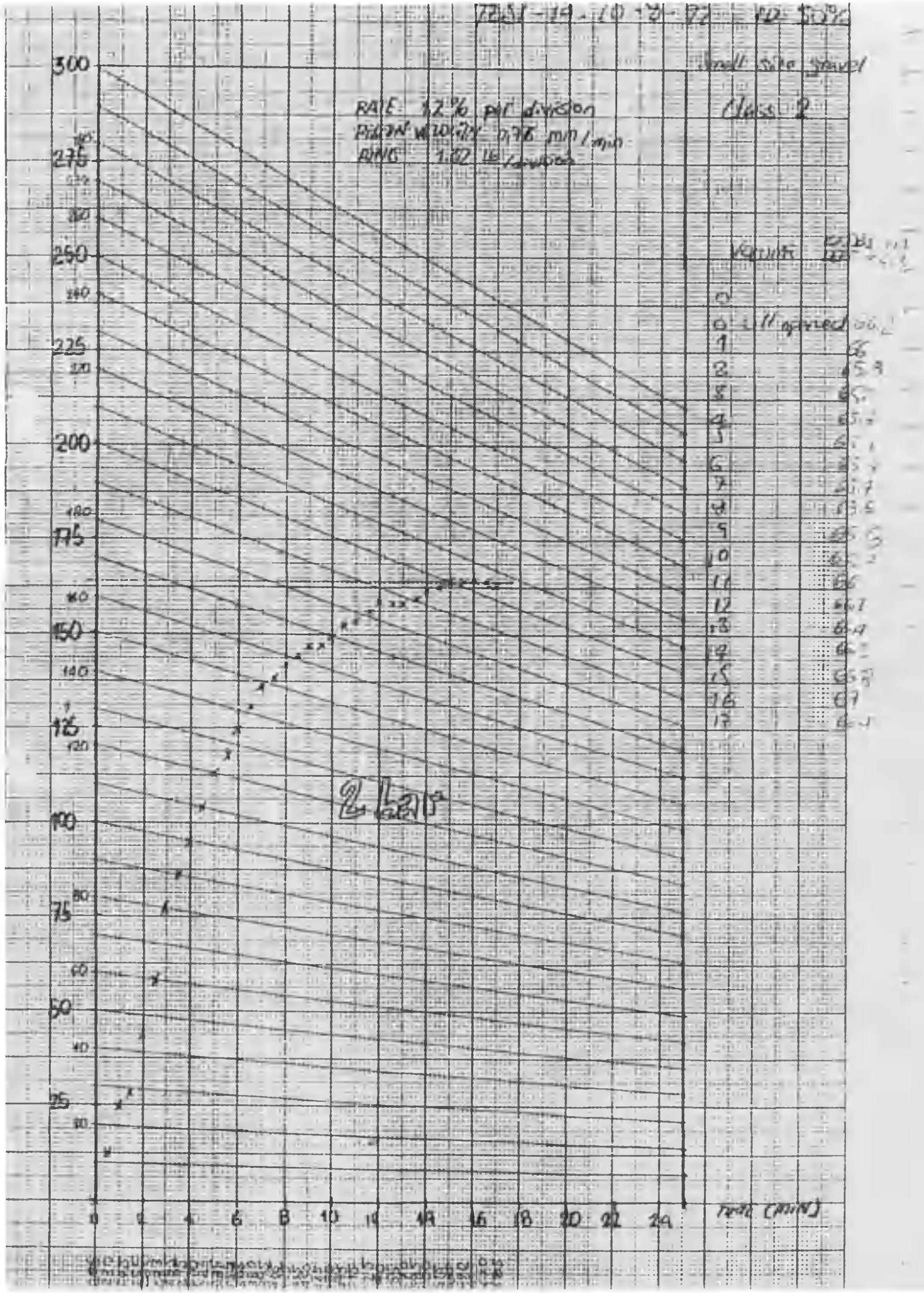

TEST 15 RD = 20%
RATE: 1.2% per division
PISTON VELOCITY 0.78 mm/min
RING 1.52 lb/division
VOLUME
TIME (MIN)

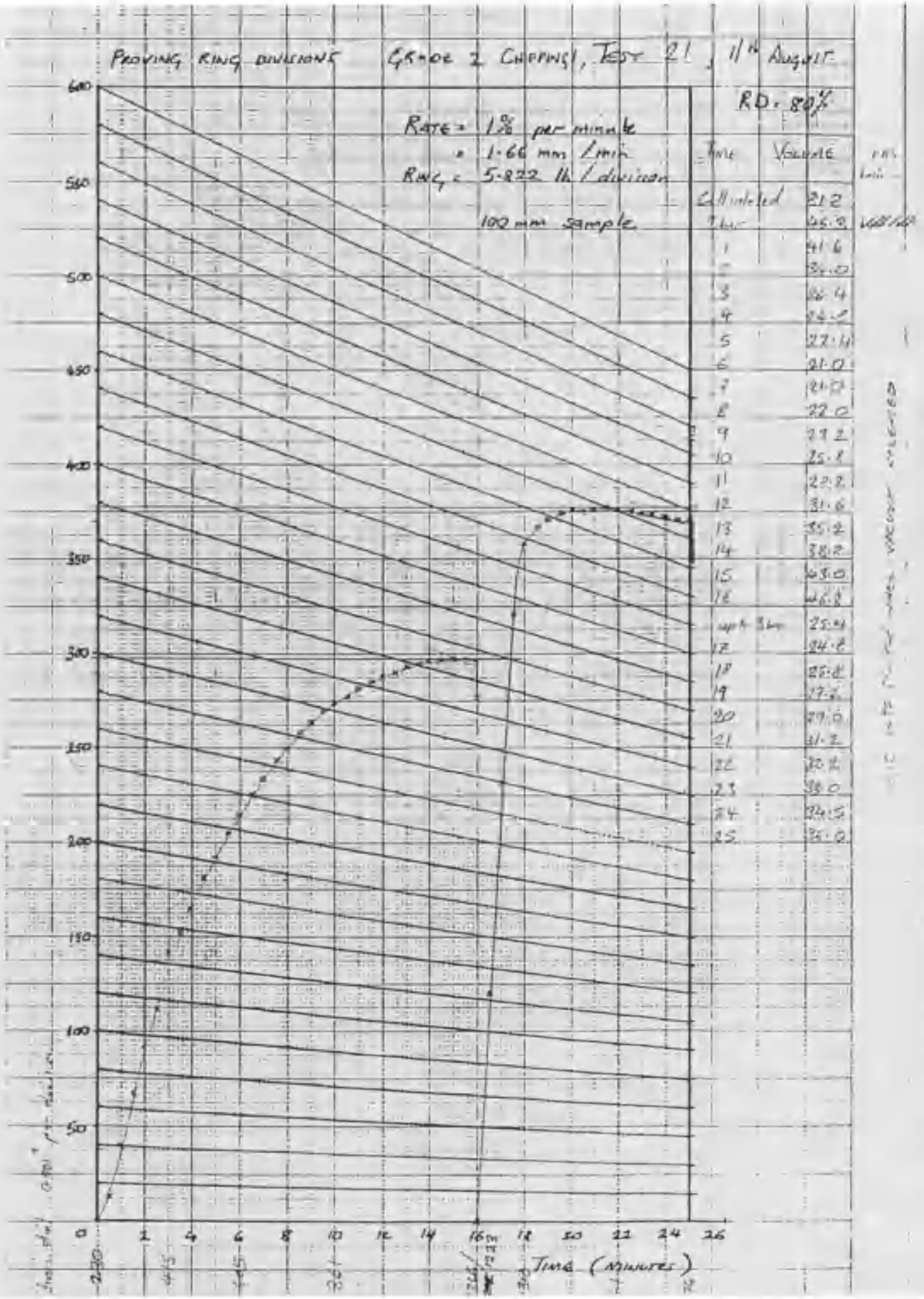

RATE: 1.2% per division
PISTON VELOCITY 0.78 mm/min
RING 1.52 lb/division
TIME (MIN)

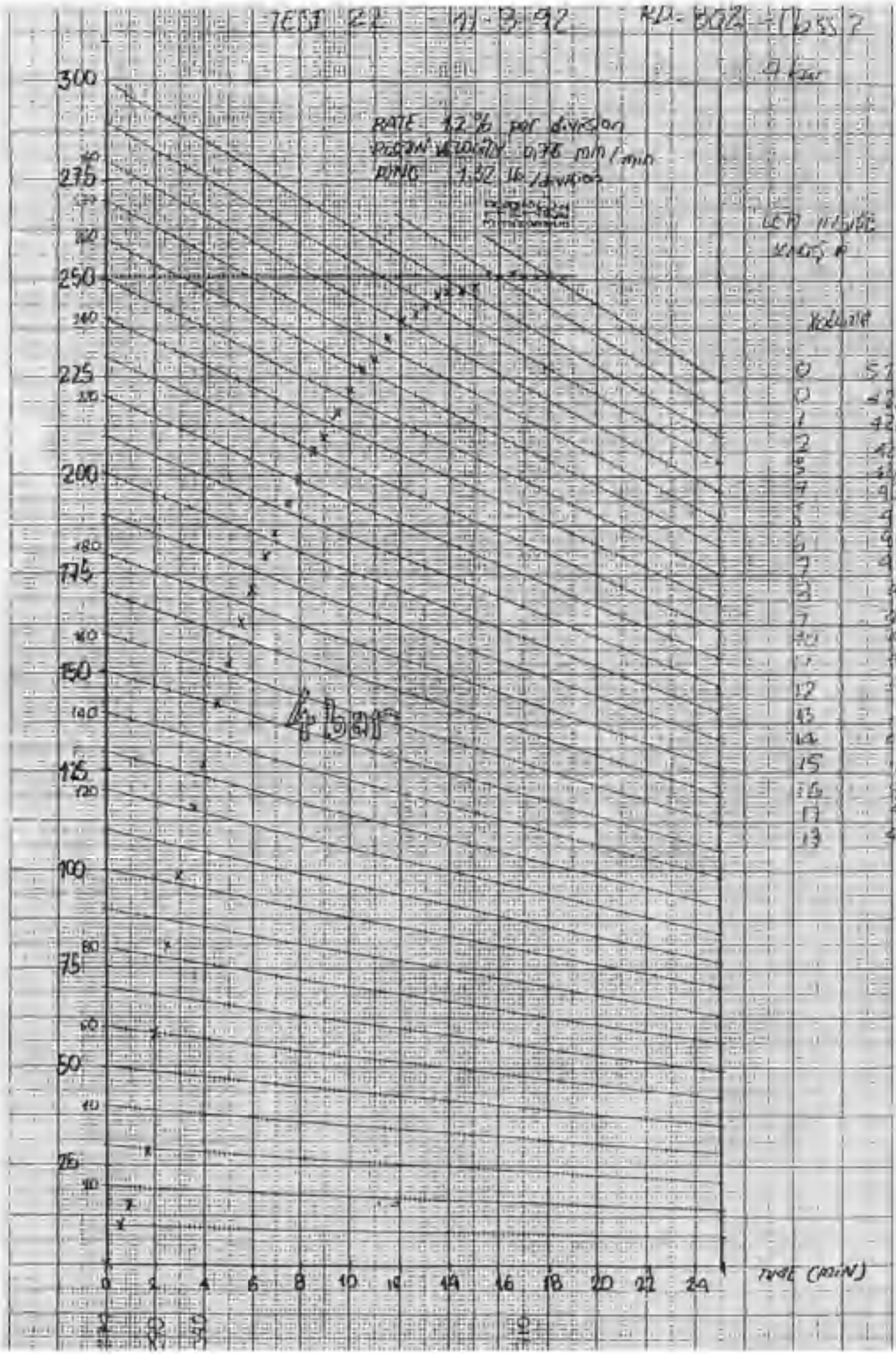


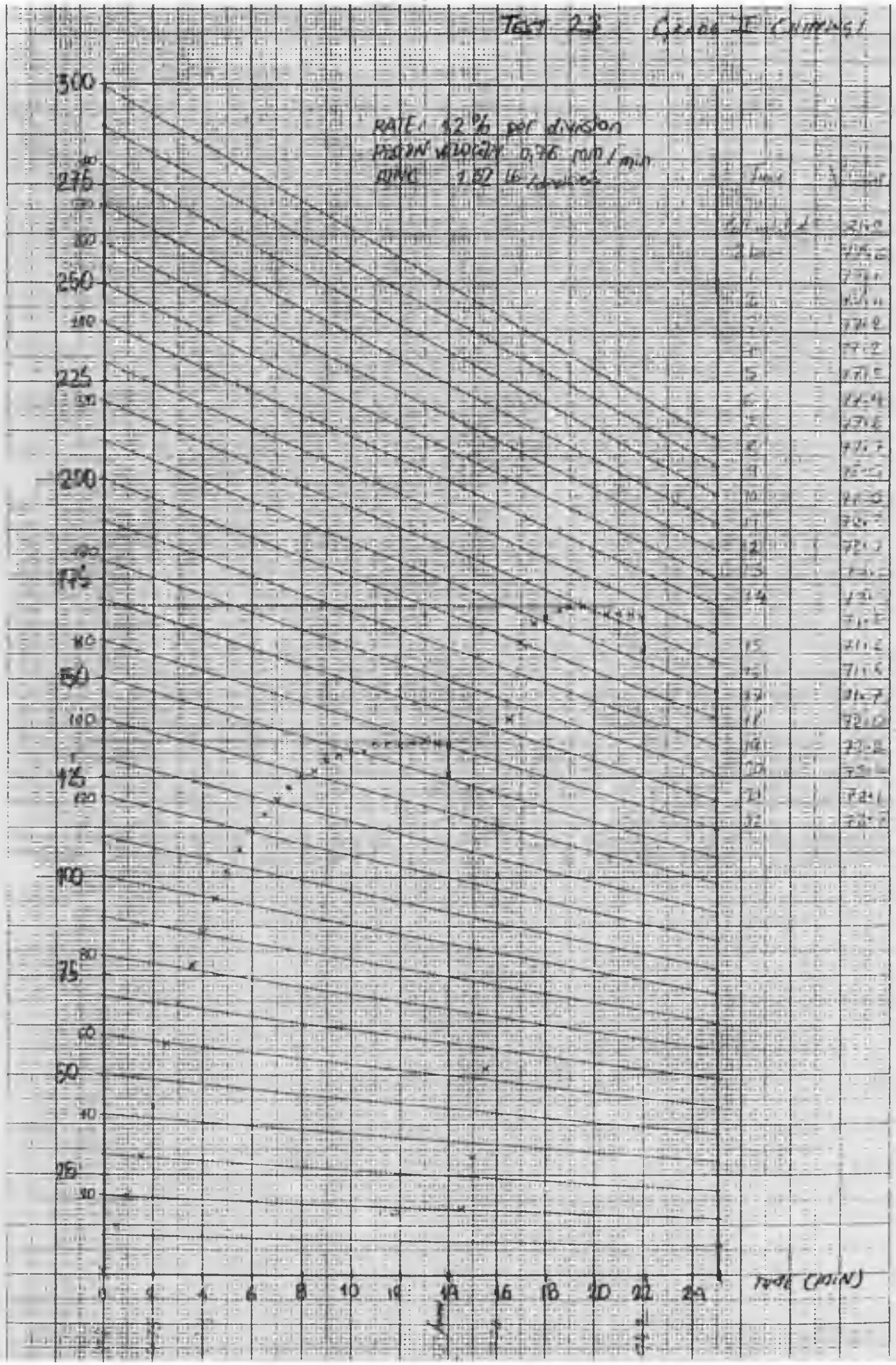
→ Continued after leakage at … Vacuum not released!

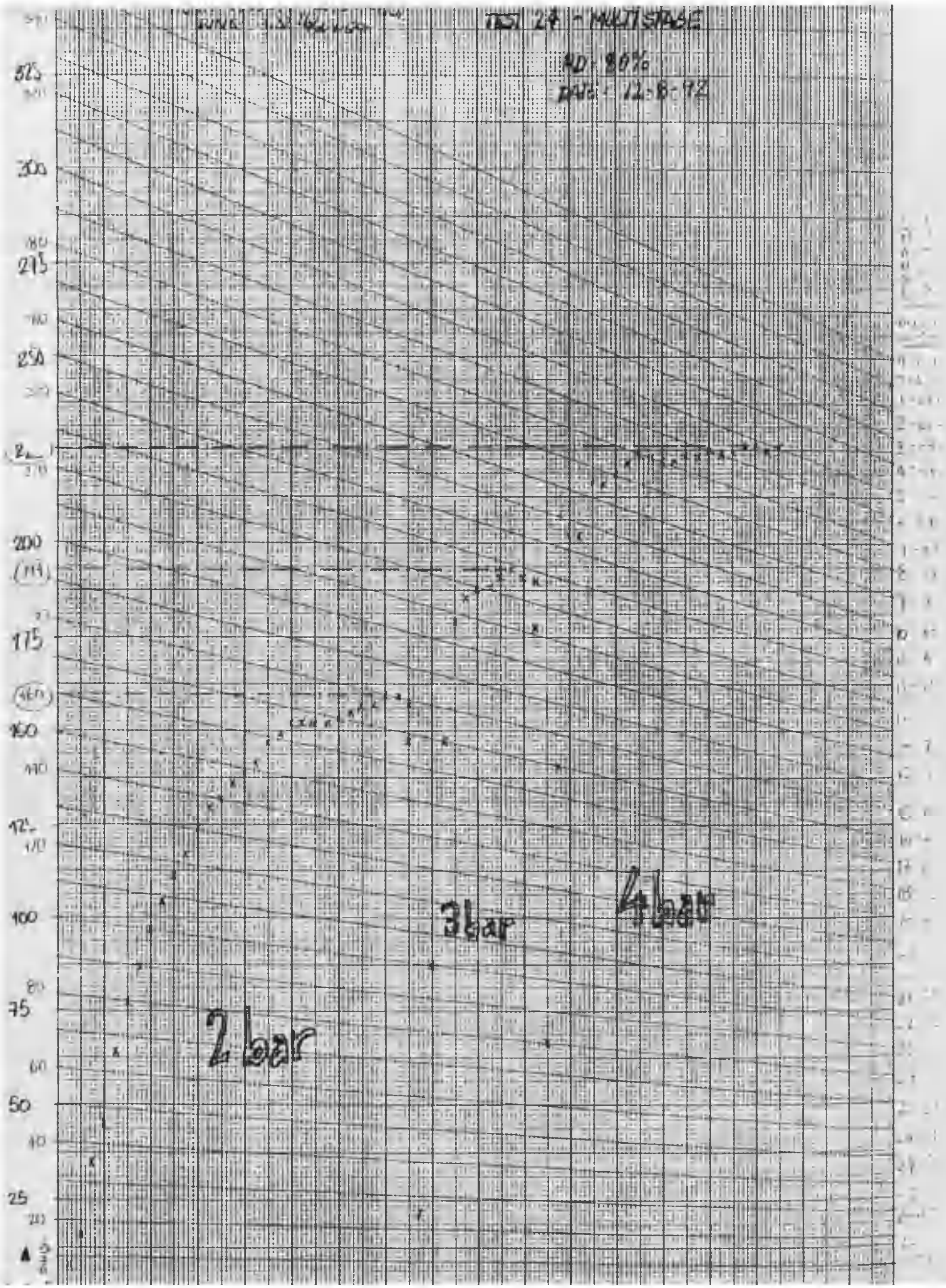
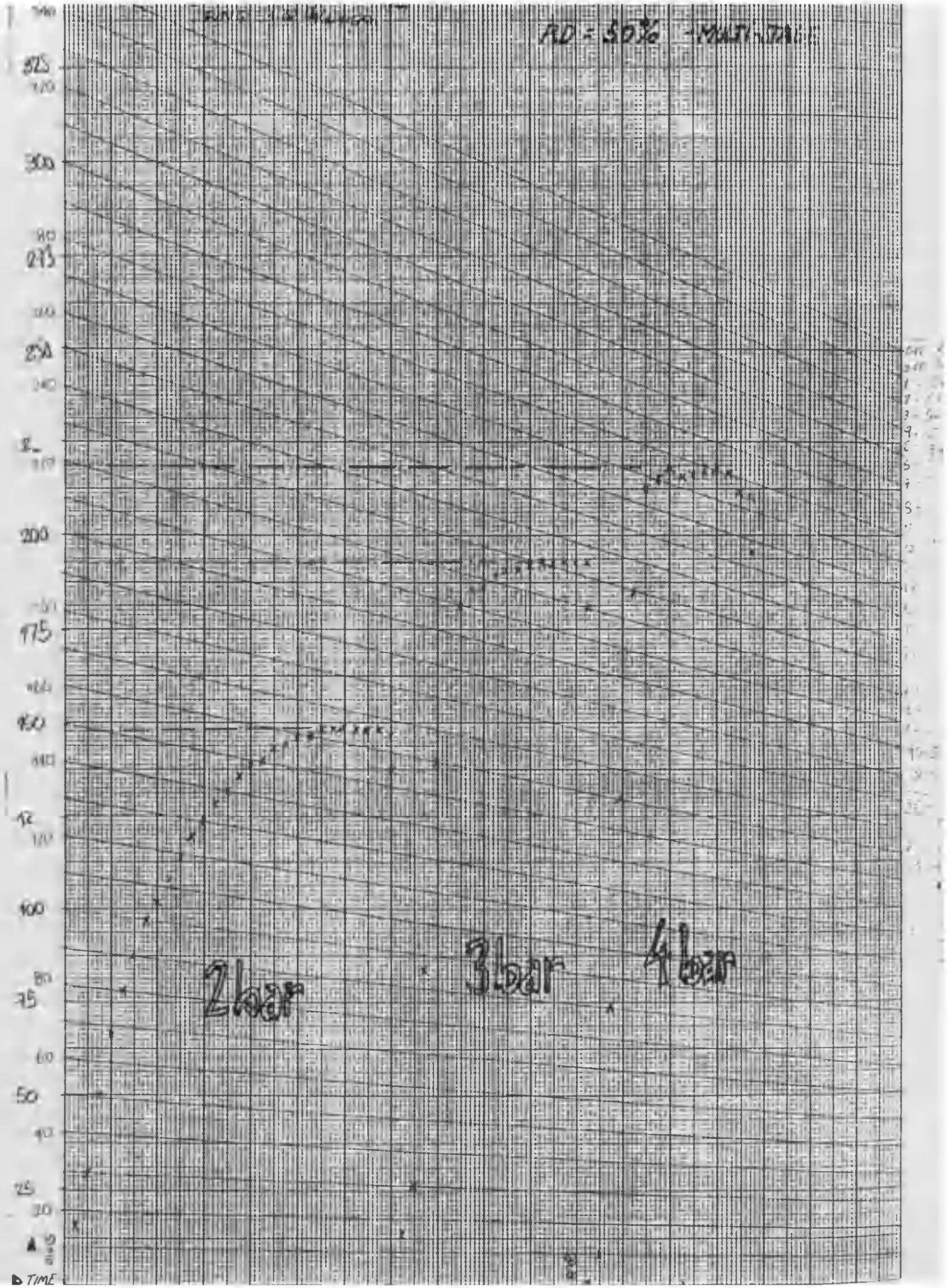



Small size gravel
Class 2
RATE 1.2% per division
Volume
2 bar
Time (min)

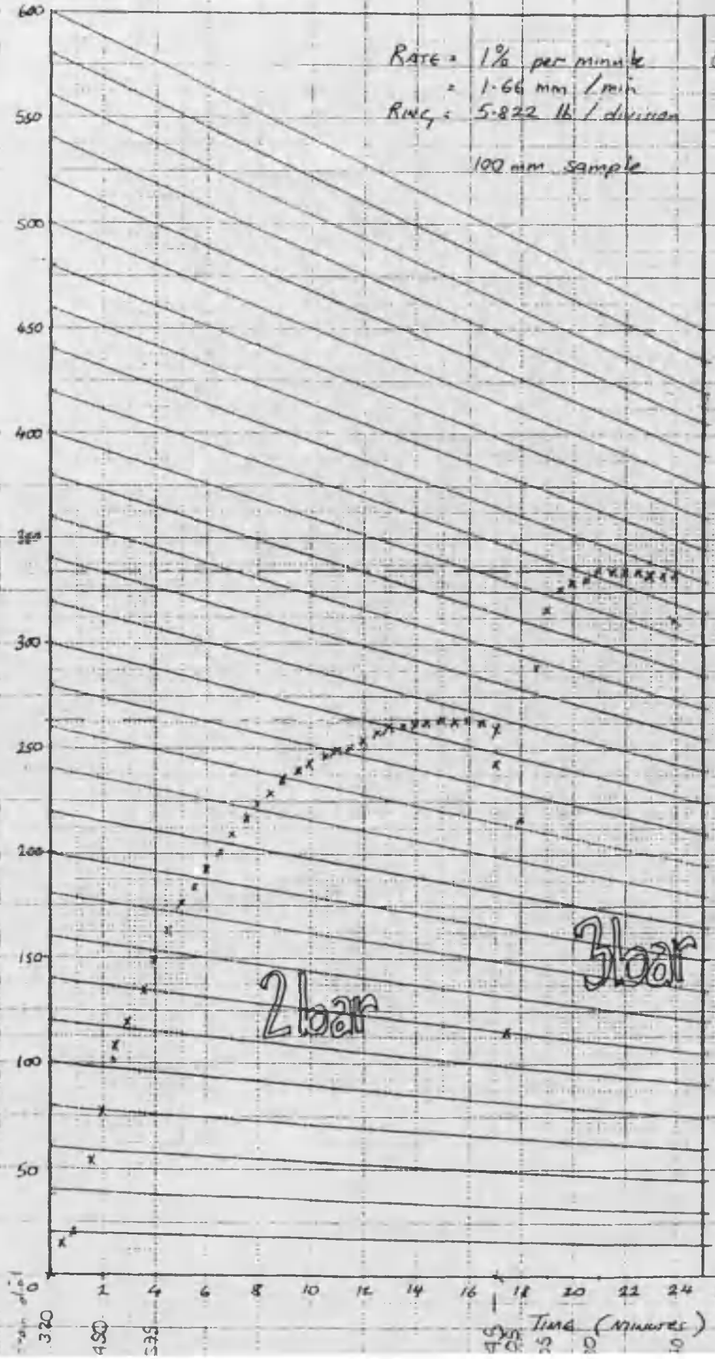

PROVING RING DIVISIONS
GRADE 2 CHIPPINGS, TEST 21, 11th August
RD = 80%
RATE = 1% per minute
= 1.66 mm / min
RING = 5.822 lb / division
100 mm sample
Time
Volume
Consolidated
Time (minutes)


TEST 22
11-3-92
4 bar
RATE 12% per division
TIME (MIN)


Test 23
RATE 12% per division
TIME (MIN)


TEST 24 - MULTISTAGE
RD - 80%
DATE - 12-8-92
2bar
3bar
4bar

RD = 50%
2bar
3bar
4bar

TEST 26 13-8-92 RD: 50% - MULTISTAGE : Class 2

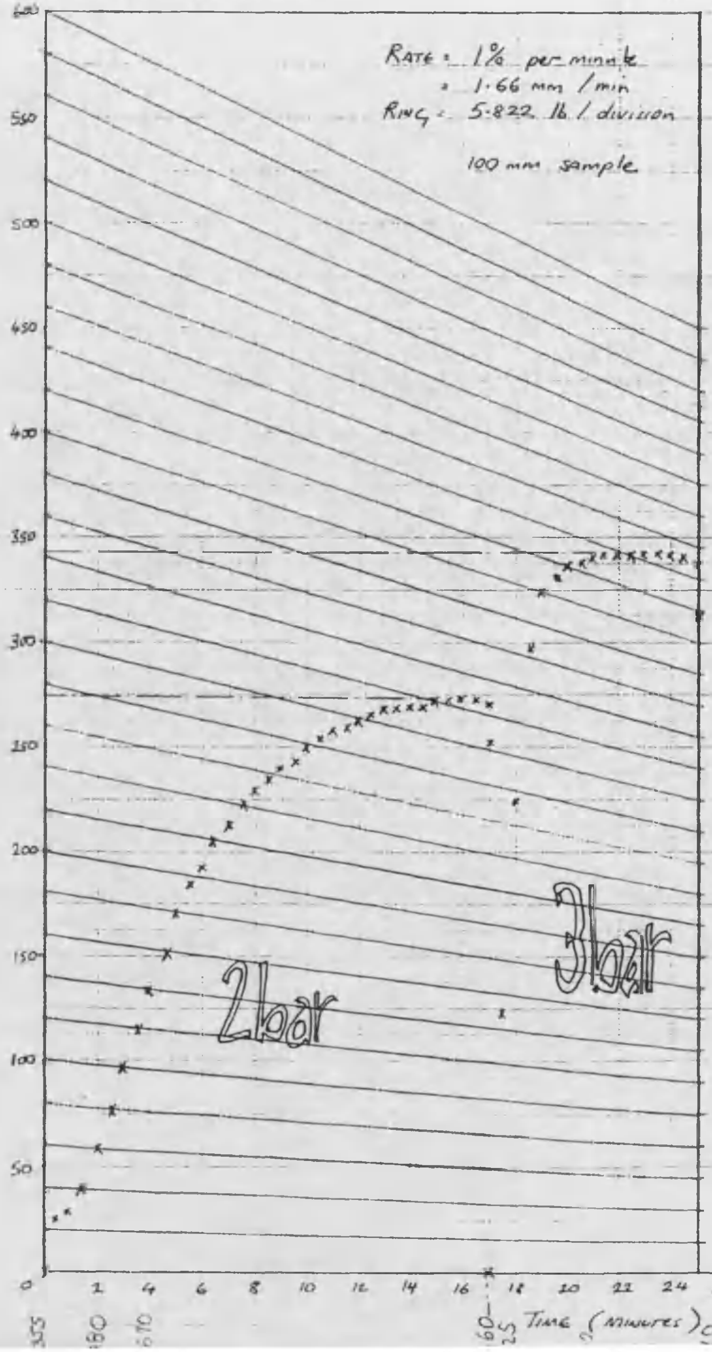


Cell isolated @ 2 bar, valves off @

Time	Volume	
0	95.8	c. isolated
0	52.9	c. opened
1	51.8	
2	43.2	
3	38	
4	33.8	
5	31.2	
6	29.9	
7	28.4	
8	28.4	
9	29.0	
10	29.8	
11	31	
12	32.2	
13	34.4	
14	36.6	
15	36	
16	41.2	
17	43.0	valves out
17	22	
18	23	
19	23.2	
20	23.2	
21	22.6	
22	22	
23	21	
24	20.4	

TEST 27 - 14-8-92 ; RD = 30%

MULTISTAGE - Class 2



0 C isolated	26
0 C opened	97.6
1	74.6
2	70
3	65
4	59.2
5	56
6	59
7	52.4
8	52.2
9	32.6
10	59
11	55.9
12	57.2
13	60
14	62
15	64.3
16	63
17	70.4
17	49.4
18	49.2
19	48.5
20	49
21	50
22	51
23	51
24	[illegible]
25	[illegible]

Test results for tests on large grained material in large cell, as detailed in section 8.4. Sample size - 254mm only.

Data output from ADU, utilising screen dumps and DIALOG software.

Includes;

1. 'Real time' plot of load response curve via DIALOG software (screen dump). Due to auto scaling these plots need to be read right to left.

2. Load vs displacement plot. XY plot from DIALOG software from logged data (screen dump).

3. Printout of all logged data. Time [secs], displacement [mm], load [KN] from non indicating load cell, and load [ADU units] from indicating load cell.

4. Calculation sheet for peak and '10%' friction angles.

CALCULATION SHEET FOR TEST .... Triax 2 and 2-2

Peak axial load difference [kN] = 48.5
Axial compression [mm] = 41.9

$\left.\begin{array}{l}\\ \\ \end{array}\right\}$ combination giving peak stress

Cross - sectional area [m^2] = 0.058

Stress difference, $\sigma_1 - \sigma_3$ [kN/m^2] = 836

Cell pressure, σ_3 [kN/m^2] = 250

Angle of friction, ϕ = **38.75°**

Axial load difference at 10% axial strain [kN] = 43.19

Stress difference, $\sigma_1 - \sigma_3$ [kN/m^2] = 767

Cell pressure, σ_3 [kN/m^2] = 250

Angle of friction, ϕ = **37.27°**

$$\text{Cross - sectional area} = \frac{\text{Sample volume}}{\text{Orig. height - axial comp.}}$$

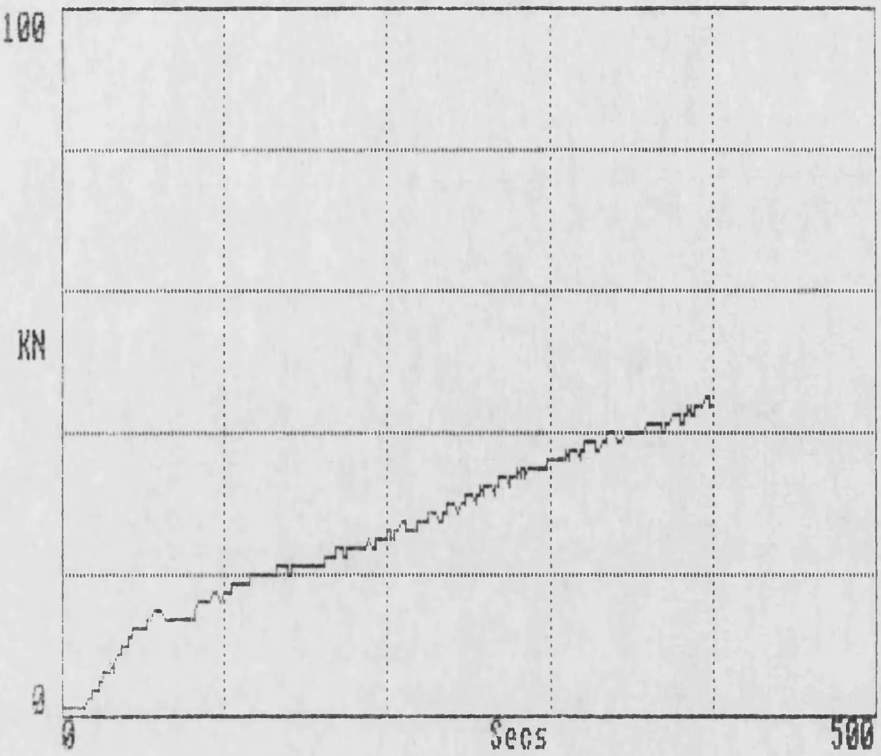
$$\text{Angle of friction determined from; } \sin \phi = \frac{\sigma_1 - \sigma_3}{\sigma_1 + \sigma_3}$$

Sample volume = 0.017 m^3,

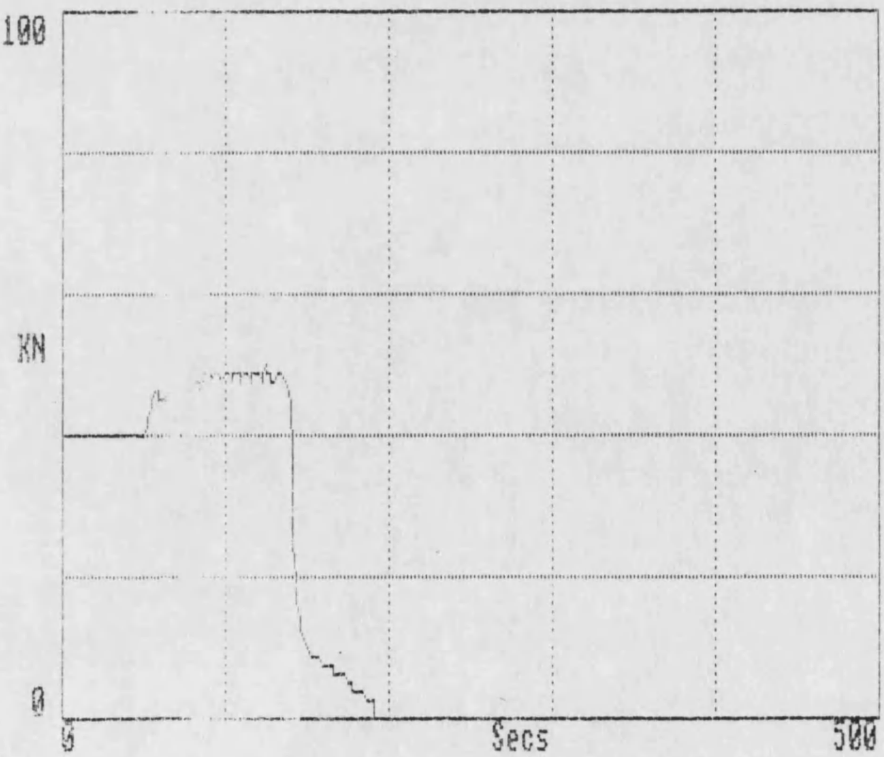
Original sample height = 335mm,

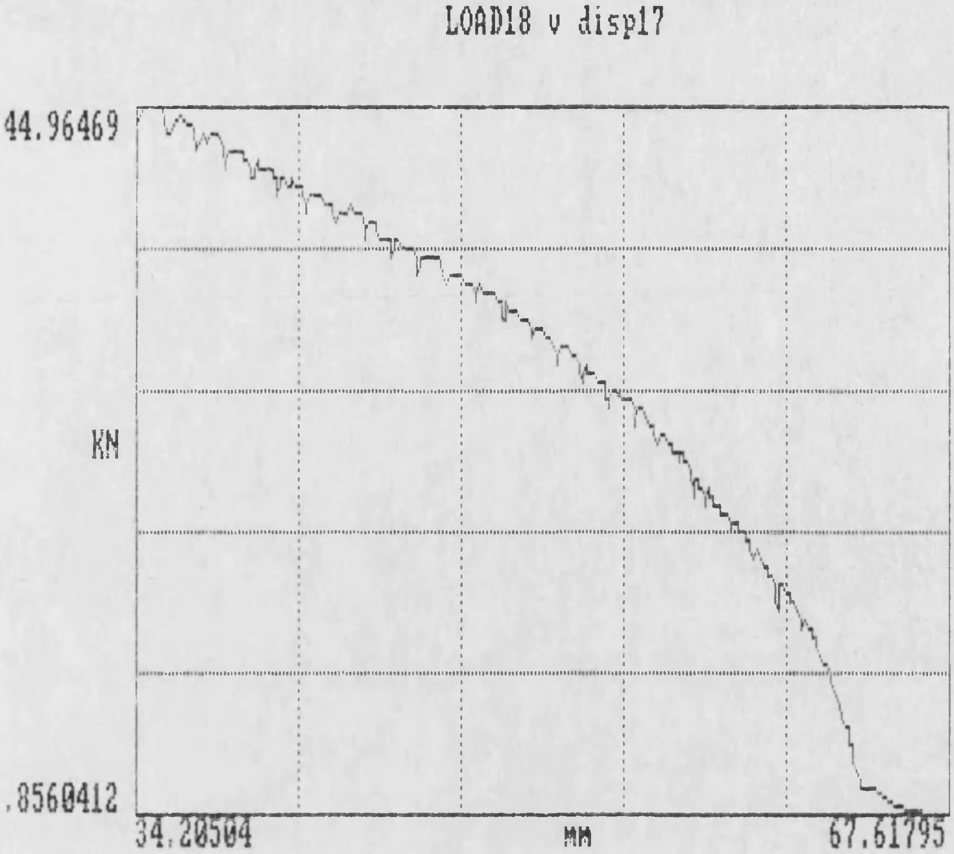
Cross - sectional area at 10% strain = 0.0563 m^2

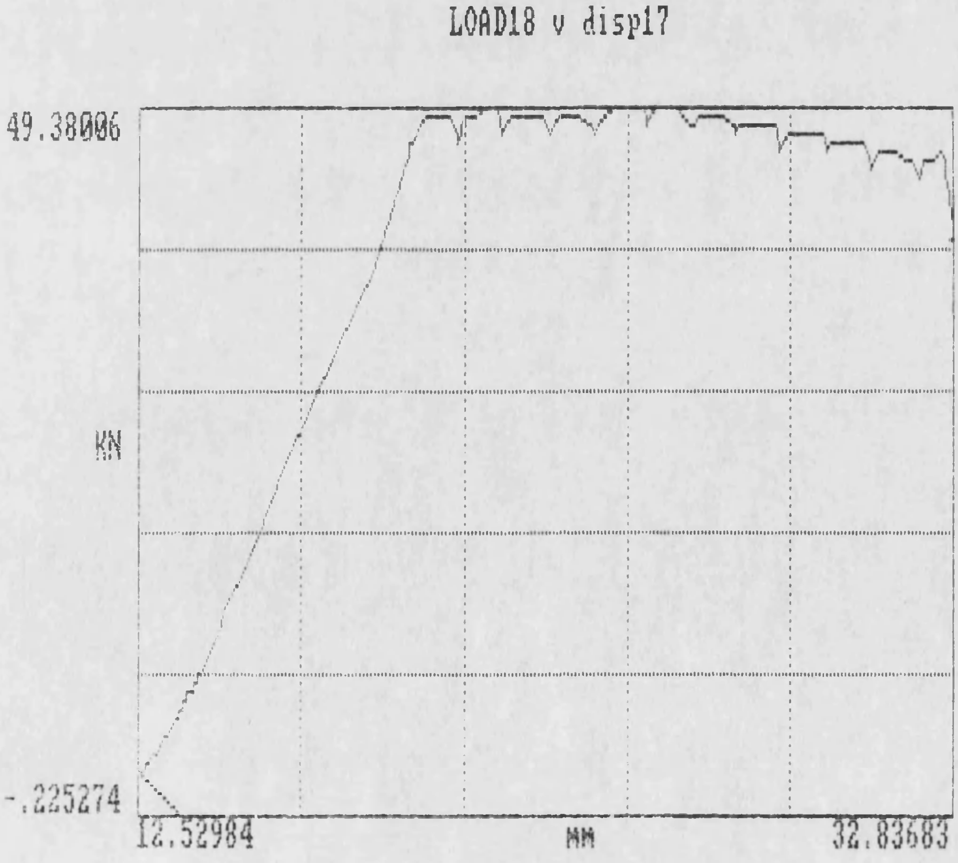
LOAD18 v Time



LOAD18 v Time




LOAD18 v disp17
44.96469
KN
.8560412
34.20504
MM
67.61795


LOAD18 v disp17
49.38006
KN
-.225274
12.52984
MM
32.83683

TRIAXIAL TEST/TRIAX2.DAT

Number of Readings 400 No. Columns 4
Date Test Started 01/01/83 Time Test Started 17-52-17

	Time Secs 1	disp17 mm 2	LOAD18 KN 3	LOAD NON 4
0	0.0	67.546	0.856	18
1	0.0	67.546	0.856	16
2	1.0	67.546	0.856	16
3	2.0	67.546	0.856	16
4	3.0	67.546	0.856	16
5	4.0	67.546	0.856	16
6	5.0	67.546	0.856	16
7	6.0	67.546	0.856	16
8	7.0	67.618	0.956	18
9	8.0	67.546	0.856	16
10	9.0	67.546	0.856	16
11	10.0	67.546	0.856	16
12	11.0	67.546	0.856	16
13	12.0	67.618	0.856	16
14	13.0	67.546	1.126	22
15	14.0	65.458	1.577	28
16	15.0	65.098	1.937	34
17	16.0	64.522	2.253	38
18	17.0	64.017	2.568	46
19	18.0	63.945	2.974	52
20	19.0	63.873	3.559	64
21	20.0	63.801	3.740	63
22	21.0	63.801	3.604	62
23	22.0	63.729	4.379	76
24	23.0	63.657	5.001	86
25	24.0	63.585	5.407	94
26	25.0	63.513	5.677	97
27	26.0	63.441	5.857	100
28	27.0	63.441	6.127	105
29	28.0	63.369	6.353	109
30	29.0	63.297	6.578	113
31	30.0	63.225	6.983	119
32	31.0	63.225	6.758	115
33	32.0	63.225	6.938	120
34	33.0	63.081	8.155	141
35	34.0	63.009	8.155	139
36	35.0	62.937	8.560	147
37	36.0	62.793	9.101	156
38	37.0	62.721	9.552	164
39	38.0	62.649	10.032	173
40	39.0	62.505	10.318	176
41	40.0	62.433	9.957	170
42	41.0	62.361	10.762	186
43	42.0	62.217	11.219	193
44	43.0	62.145	11.624	200
45	44.0	62.001	11.940	207
46	45.0	61.929	12.165	209
47	46.0	61.785	12.345	212
48	47.0	61.713	12.751	220
49	48.0	61.641	13.021	224
50	49.0	61.569	12.573	217

TRIAXIAL TEST/TRIAX2.DAT

Number of Readings 400 No. Columns 4
Date Task Started 01/01/83 Time Task Started 17-52-17

	Time Secs 1	disp17 mm 2	LOAD18 KN 3	LOAD NON 4
51	50.0	61.569	12.480	214
52	51.0	61.497	12.300	211
53	52.0	61.497	12.931	223
54	53.0	61.353	13.652	237
55	54.0	61.281	13.922	240
56	55.0	61.137	14.237	245
57	56.0	61.065	14.418	248
58	57.0	60.921	14.688	253
59	58.0	60.849	14.958	258
60	59.0	60.705	15.183	261
61	60.0	60.633	14.823	254
62	61.0	60.633	14.598	250
63	62.0	60.633	14.463	248
64	63.0	60.633	14.327	247
65	64.0	60.633	14.237	245
66	65.0	60.561	14.147	243
67	66.0	60.561	14.102	242
68	67.0	60.561	14.012	242
69	68.0	60.561	13.967	240
70	69.0	60.561	13.922	240
71	70.0	60.561	13.877	239
72	71.0	60.561	13.877	239
73	72.0	60.561	13.832	239
74	73.0	60.561	13.787	237
75	74.0	60.561	13.742	237
76	75.0	60.561	13.742	235
77	76.0	60.561	13.697	235
78	77.0	60.561	13.697	235
79	78.0	60.561	13.652	234
80	79.0	60.561	13.652	235
81	80.0	60.561	13.607	234
82	81.0	60.489	14.147	243
83	82.0	60.489	15.183	262
84	83.0	60.345	15.859	272
85	84.0	60.345	15.949	274
86	85.0	60.273	15.814	269
87	86.0	60.273	15.679	269
88	87.0	60.201	15.724	270
89	88.0	60.201	16.040	275
90	89.0	60.057	16.445	284
91	90.0	60.057	16.445	282
92	91.0	59.985	16.490	282
93	92.0	59.913	16.670	[illegible]
94	93.0	59.841	16.896	290
95	94.0	59.769	17.256	[illegible]
96	95.0	59.697	17.346	296
97	96.0	59.625	16.986	[illegible]
98	97.0	59.625	16.760	[illegible]
99	98.0	59.625	16.625	[illegible]
100	99.0	59.553	16.941	[illegible]
101	100.0	59.481	17.211	[illegible]

TRIAXIAL TEST/TRIAX2.DAT

Number of Readings 400 No. Columns 4
Date Task Started 01/01/83 Time Task Started 17-52-17

	Time Secs 1	disp17 mm 2	LOAD18 KN 3	LOAD NON 4
102	101.0	59.481	17.391	297
103	102.0	59.481	17.571	301
104	103.0	59.409	17.797	304
105	104.0	59.337	18.022	308
106	105.0	59.265	18.247	311
107	106.0	59.193	18.427	314
108	107.0	59.049	18.472	316
109	108.0	58.977	18.698	319
110	109.0	58.905	18.923	324
111	110.0	58.833	19.103	327
112	111.0	58.761	19.193	327
113	112.0	58.689	19.148	327
114	113.0	58.617	18.833	321
115	114.0	58.617	18.653	318
116	115.0	58.617	18.923	322
117	116.0	58.545	19.374	331
118	117.0	58.473	19.464	332
119	118.0	58.473	19.419	331
120	119.0	58.401	19.644	335
121	120.0	58.329	19.644	334
122	121.0	58.329	19.599	333
123	122.0	58.257	19.689	335
124	123.0	58.257	19.779	336
125	124.0	58.185	19.914	338
126	125.0	58.185	20.094	342
127	126.0	58.113	20.320	347
128	127.0	58.041	20.365	346
129	128.0	58.041	20.410	346
130	129.0	57.969	20.410	346
131	130.0	57.697	20.365	347
132	131.0	57.897	20.500	349
133	132.0	57.825	20.635	350
134	133.0	57.825	20.770	353
135	134.0	57.752	20.950	356
136	135.0	57.752	20.996	357
137	136.0	57.680	21.041	356
138	137.0	57.608	20.905	355
139	138.0	57.608	20.680	351
140	139.0	57.536	20.500	348
141	140.0	57.536	20.410	346
142	141.0	57.536	20.500	348
143	142.0	57.536	20.860	355
144	143.0	57.464	20.996	357
145	144.0	57.464	21.041	357
146	145.0	57.464	21.086	358
147	146.0	57.392	21.086	357
148	147.0	57.392	21.176	359
149	148.0	57.392	21.221	360
150	149.0	57.320	21.401	363
151	150.0	57.320	21.536	365
152	151.0	57.248	21.671	368

TRIAXIAL TEST/TRIAX2.DAT

Number of Readings 400 No. Columns 4
Date Task Started 01/01/83 Time Task Started 17-52-17

	Time Secs 1	disp17 mm 2	LOAD18 KN 3	LOAD NON 4
153	152.0	57.248	21.807	371
154	153.0	57.176	21.536	365
155	154.0	57.176	21.356	361
156	155.0	57.176	21.266	360
157	156.0	57.176	21.131	359
158	157.0	57.104	21.041	357
159	158.0	57.104	20.950	355
160	159.0	57.104	20.860	355
161	160.0	57.104	20.815	353
162	161.0	57.104	21.266	360
163	162.0	57.032	21.942	372
164	163.0	57.032	22.392	380
165	164.0	56.960	22.572	383
166	165.0	56.960	22.618	383
167	166.0	56.888	22.708	385
168	167.0	56.888	22.843	387
169	168.0	56.816	22.978	389
170	169.0	56.744	23.158	392
171	170.0	56.672	23.203	393
172	171.0	56.600	23.203	393
173	172.0	56.600	23.158	391
174	173.0	56.528	22.888	387
175	174.0	56.528	22.708	385
176	175.0	56.528	22.753	385
177	176.0	56.456	23.428	397
178	177.0	56.384	23.699	402
179	178.0	56.384	23.654	401
180	179.0	56.312	23.654	401
181	180.0	56.240	23.699	402
182	181.0	56.168	23.834	402
183	182.0	56.168	23.789	402
184	183.0	56.096	23.744	402
185	184.0	56.024	24.014	407
186	185.0	56.024	24.104	408
187	186.0	55.952	24.375	413
188	187.0	55.808	24.375	412
189	188.0	55.808	24.420	413
190	189.0	55.736	24.555	414
191	190.0	55.664	24.285	409
192	191.0	55.664	24.014	405
193	192.0	55.592	23.834	403
194	193.0	55.592	24.194	410
195	194.0	55.520	24.645	416
196	195.0	55.448	25.005	423
197	196.0	55.448	25.005	422
198	197.0	55.376	25.050	423
199	198.0	55.304	25.231	426
200	199.0	55.232	25.456	430
201	200.0	55.088	25.681	433
202	201.0	55.016	26.132	442
203	202.0	54.800	26.087	439

[illegible]

Number of Readings 400 No. Columns 4
Date Task Started 01/01/85 Time Task Started 17-52-17

	Time Secs 1	disp17 mm 2	LOAD18 KN 3	LOAD NON 4
204	203.0	54.728	25.456	429
205	204.0	54.728	25.321	427
206	205.0	54.656	26.177	442
207	206.0	54.512	26.537	448
208	207.0	54.368	26.808	453
209	208.0	54.224	26.898	454
210	209.0	54.008	27.168	458
211	210.0	53.864	27.438	463
212	211.0	53.792	27.123	456
213	212.0	53.720	26.627	449
214	213.0	53.720	26.357	444
215	214.0	53.648	26.177	442
216	215.0	53.648	26.042	440
217	216.0	53.648	26.357	444
218	217.0	53.576	26.672	450
219	218.0	53.576	26.672	450
220	219.0	53.504	26.988	455
221	270.0	53.432	27.619	467
222	221.0	53.360	27.844	469
223	222.0	53.288	27.889	470
224	223.0	53.216	27.934	470
225	224.0	53.144	27.979	471
226	225.0	53.072	28.294	478
227	226.0	52.928	28.430	478
228	227.0	52.928	28.385	478
229	228.0	52.784	28.655	482
230	229.0	52.712	28.880	487
231	230.0	52.640	28.339	477
232	231.0	52.568	28.024	471
233	232.0	52.568	27.844	469
234	233.0	52.568	27.799	467
235	234.0	52.496	28.520	481
236	235.0	52.424	29.060	490
237	236.0	52.352	29.286	493
238	237.0	52.208	29.556	498
239	238.0	52.064	29.781	502
240	239.0	51.920	30.007	505
241	240.0	51.776	30.142	506
242	241.0	51.632	30.187	508
243	242.0	51.560	29.511	496
244	243.0	51.488	29.196	491
245	244.0	51.488	29.331	495
246	245.0	51.416	30.142	508
247	246.0	51.272	30.367	512
248	247.0	51.200	30.592	514
249	248.0	51.056	30.772	517
250	249.0	50.911	30.998	522
251	250.0	50.767	31.088	522
252	251.0	50.623	31.133	524
253	252.0	50.551	31.313	526
254	253.0	50.407	30.727	517

TRIAXIAL TEST/TRIAX2.DAT

Number of Readings 400 No. Columns 4
Date Task Started 01/01/85 Time Task Started 17-52-17

	Time Secs 1	disp17 mm 2	LOAD18 KN 3	LOAD NON 4
255	254.0	50.407	30.412	512
256	255.0	50.407	30.998	523
257	256.0	50.263	31.538	530
258	257.0	50.119	31.989	539
259	258.0	50.047	31.854	536
260	259.0	49.903	32.304	543
261	260.0	49.759	32.304	542
262	261.0	49.687	32.259	541
263	262.0	49.543	32.530	547
264	263.0	49.399	32.575	547
265	264.0	49.327	31.944	536
266	265.0	49.255	31.628	531
267	266.0	49.255	32.665	550
268	267.0	49.111	32.890	552
269	268.0	49.039	32.800	551
270	269.0	48.895	33.341	560
271	270.0	48.751	33.386	561
272	271.0	48.607	33.386	560
273	272.0	48.463	33.566	564
274	273.0	48.319	33.881	568
275	274.0	48.175	33.115	554
276	275.0	48.103	32.710	548
277	276.0	48.103	33.431	562
278	277.0	47.959	34.016	572
279	278.0	47.815	34.016	570
280	279.0	47.671	34.197	573
281	280.0	47.527	34.512	579
282	281.0	47.383	34.332	574
283	282.0	47.239	34.557	580
284	283.0	47.095	34.737	583
285	284.0	46.951	34.016	569
286	285.0	46.951	33.926	569
287	286.0	46.879	34.737	582
288	287.0	46.663	35.413	593
289	288.0	46.519	35.368	593
290	289.0	46.375	35.548	595
291	290.0	46.303	35.593	596
292	291.0	46.159	35.368	592
293	292.0	46.087	35.503	595
294	293.0	46.015	35.548	595
295	294.0	45.871	35.323	590
296	295.0	45.871	34.872	585
297	296.0	45.799	34.737	581
298	297.0	45.727	35.413	595
299	298.0	45.655	35.909	602
300	299.0	45.583	36.134	605
301	300.0	45.439	36.224	605
302	301.0	45.367	36.269	606
303	302.0	45.223	36.359	608
304	303.0	45.079	36.359	609
305	304.0	45.007	36.494	611

TRIAXIAL TEST/TRIAX2.DAT

Number of Readings 400 No. Columns 4
Date Task Started 01/01/83 Time Task Started 17-52-17

	Time Secs 1	disp17 mm 2	LOAD18 KN 3	LOAD NON 4
306	305.0	44.863	36.810	616
307	306.0	44.791	36.134	604
308	307.0	44.719	35.728	599
309	308.0	44.719	35.864	602
310	309.0	44.647	36.539	613
311	310.0	44.503	36.900	617
312	311.0	44.359	36.855	616
313	312.0	44.287	36.900	617
314	313.0	44.143	37.395	626
315	314.0	44.070	37.576	629
316	315.0	43.854	37.846	634
317	316.0	43.710	37.846	632
318	317.0	43.638	37.305	623
319	318.0	43.566	36.855	616
320	319.0	43.566	36.990	620
321	320.0	43.422	38.116	639
322	321.0	43.278	38.297	640
323	322.0	43.134	38.252	639
324	323.0	42.990	38.657	646
325	324.0	42.846	38.432	642
326	325.0	42.702	38.567	644
327	326.0	42.558	38.612	646
328	327.0	42.486	38.477	642
329	328.0	42.414	37.891	633
330	329.0	42.342	37.576	627
331	330.0	42.342	37.756	631
332	331.0	42.270	38.387	643
333	332.0	42.198	38.792	648
334	333.0	42.126	38.882	650
335	334.0	41.982	39.153	655
336	335.0	41.838	39.423	659
337	336.0	41.766	39.423	659
338	337.0	41.622	39.423	659
339	338.0	41.478	39.378	659
340	339.0	41.406	39.468	660
341	340.0	41.334	39.333	657
342	341.0	41.262	38.792	648
343	342.0	41.190	38.477	642
344	343.0	41.190	38.342	641
345	344.0	41.118	38.927	652
346	345.0	41.046	39.513	660
347	346.0	40.974	39.783	664
348	347.0	40.902	39.738	664
349	348.0	40.830	39.828	665
350	349.0	40.686	39.964	668
351	350.0	40.614	40.324	673
352	351.0	40.542	40.189	671
353	352.0	40.398	40.189	672
354	353.0	40.326	40.369	674
355	354.0	40.182	40.414	675
356	355.0	40.110	40.054	668

TRIAXIAL TEST/TRIAX2.DAT

Number of Readings 400 No. Columns 4
Date Task Started 01/01/83 Time Task Started 17-52-17

	Time Secs 1	disp17 mm 2	LOAD18 KN 3	LOAD NON 4
357	356.0	40.038	39.648	661
358	357.0	40.038	39.468	659
359	358.0	39.966	40.730	682
360	359.0	39.822	40.730	680
361	360.0	39.750	41.180	687
362	361.0	39.606	41.225	687
363	362.0	39.462	41.090	685
364	363.0	39.390	40.865	682
365	364.0	39.318	40.955	684
366	365.0	39.246	41.135	687
367	366.0	39.174	41.405	691
368	367.0	39.102	41.180	686
369	368.0	39.030	40.684	680
370	369.0	38.958	40.414	674
371	370.0	38.958	40.369	673
372	371.0	38.886	41.315	691
373	372.0	38.814	41.766	698
374	373.0	38.670	41.856	699
375	374.0	38.598	42.036	701
376	375.0	38.454	42.036	701
377	376.0	38.310	41.946	700
378	377.0	38.166	42.261	705
379	378.0	38.094	42.306	706
380	379.0	37.950	42.126	703
381	380.0	37.878	41.541	692
382	381.0	37.806	41.315	689
383	382.0	37.734	42.622	712
384	383.0	37.518	43.117	720
385	384.0	37.301	43.388	724
386	385.0	37.085	43.027	717
387	386.0	36.869	43.523	727
388	387.0	36.725	42.622	709
389	388.0	36.653	42.171	703
390	389.0	36.509	43.703	731
391	390.0	36.293	43.973	733
392	391.0	36.005	44.244	736
393	392.0	35.717	44.109	735
394	393.0	35.573	43.253	720
395	394.0	35.429	43.523	726
396	395.0	35.213	44.920	750
397	396.0	34.781	44.965	749
398	397.0	34.493	44.739	745
399	398.0	34.277	43.928	730
400	399.0	34.205	43.253	720

* 10% strain

RIAXIAL TEST/TRIAX2-2.DAT

umber of Readings 215 No. Columns 4
ate Task Started 01/01/83 Time Task Started 18-03-51

	Time Secs 1	displ7 mm 2	LOAD18 KN 3	LOAD NON 4
0	0.0	32.837	40.369	673
1	0.0	32.837	40.369	673
2	1.0	32.837	40.414	673
3	2.0	32.837	40.369	672
4	3.0	32.837	40.369	674
5	4.0	32.837	40.369	673
6	5.0	32.837	40.369	673
7	6.0	32.837	40.369	672
8	7.0	32.837	40.369	673
9	8.0	32.837	40.369	673
10	9.0	32.837	40.369	673
11	10.0	32.837	40.369	674
12	11.0	32.837	40.369	673
13	12.0	32.837	40.369	673
14	13.0	32.837	40.369	673
15	14.0	32.837	40.369	673
16	15.0	32.837	40.369	673
17	16.0	32.837	40.324	672
18	17.0	32.837	40.324	672
19	18.0	32.837	40.324	672
20	19.0	32.837	40.369	672
21	20.0	32.837	40.324	672
22	21.0	32.837	40.324	673
23	22.0	32.837	40.369	673
24	23.0	32.837	40.324	672
25	24.0	32.837	40.324	672
26	25.0	32.837	40.324	672
27	26.0	32.837	40.324	672
28	27.0	32.837	40.324	673
29	28.0	32.837	40.324	672
30	29.0	32.837	40.324	672
31	30.0	32.837	40.324	672
32	31.0	32.837	40.324	671
33	32.0	32.837	40.324	672
34	33.0	32.765	40.324	671
35	34.0	32.837	40.324	672
36	35.0	32.837	40.324	671
37	36.0	32.837	40.324	672
38	37.0	32.837	40.324	672
39	38.0	32.837	40.324	671
40	39.0	32.837	40.324	671
41	40.0	32.837	40.279	672
42	41.0	32.837	40.324	671
43	42.0	32.837	40.279	671
44	43.0	32.765	40.279	672
45	44.0	32.837	40.324	671
46	45.0	32.837	40.324	672
47	46.0	32.837	40.324	671
48	47.0	32.837	40.324	672
49	48.0	32.837	40.279	672
50	49.0	32.837	40.324	672

TRIAXIAL TEST/TRIAX2-2.DAT

Number of Readings 215 No. Columns 4
Date Task Started 01/01/83 Time Task Started 18-03-51

	Time Secs 1	displ7 mm 2	LOAD18 KN 3	LOAD NON 4
51	50.0	32.837	40.279	671
52	51.0	32.837	40.279	672
53	52.0	32.837	40.955	684
54	53.0	32.765	42.261	706
55	54.0	32.765	43.253	721
56	55.0	32.693	44.469	742
57	56.0	32.693	45.686	760
58	57.0	32.549	46.001	764
59	58.0	32.405	45.866	763
60	59.0	32.261	45.686	759
61	60.0	32.117	45.550	755
62	61.0	32.045	44.694	743
63	62.0	31.973	44.694	744
64	63.0	31.829	45.595	759
65	64.0	31.685	45.731	760
66	65.0	31.469	46.046	766
67	66.0	31.325	46.136	767
68	67.0	31.181	46.271	768
69	68.0	31.037	46.136	767
70	69.0	30.893	45.641	757
71	70.0	30.821	45.100	749
72	71.0	30.749	46.181	768
73	72.0	30.605	46.722	777
74	73.0	30.460	46.722	775
75	74.0	30.316	47.172	784
76	75.0	30.100	47.127	783
77	76.0	29.956	47.172	783
78	77.0	29.812	46.677	774
79	78.0	29.740	46.001	763
80	79.0	29.596	47.398	789
81	80.0	29.380	47.758	793
82	81.0	29.164	47.803	793
83	82.0	28.948	47.533	789
84	83.0	28.804	47.533	789
85	84.0	28.588	47.172	781
86	95.0	28.516	46.452	770
87	86.0	28.372	48.073	800
88	87.0	28.156	48.344	802
89	88.0	27.868	48.299	800
90	89.0	27.724	48.164	799
91	90.0	27.508	48.254	800
92	91.0	27.436	47.308	784
93	92.0	27.364	47.848	795
94	93.0	27.148	48.659	807
95	94.0	26.860	48.704	809
96	95.0	26.716	48.524	805
97	96.0	26.500	48.569	805
98	97.0	26.356	47.893	793
99	98.0	26.284	47.848	794
100	99.0	26.140	49.020	813
101	100.0	25.924	49.155	815

[illegible] TEST/[illegible]2.DAT

Number of Readings 215 No. Columns 4
Date Task Started 01/01/83 Time Task Started 18-03-51

	Time Secs 1	disp17 mm 2	LOAD18 KN 3	LOAD NOM 4	
102	101.0	25.636	49.335	817	* peak
103	102.0	25.420	49.155	814	
104	103.0	25.276	48.975	812	
105	104.0	25.132	48.073	796	
106	105.0	25.060	49.110	816	
107	106.0	24.772	49.290	817	
108	107.0	24.412	49.290	817	
109	108.0	24.196	48.659	805	
110	109.0	23.980	48.434	303	
111	110.0	23.908	47.443	785	
112	111.0	23.764	48.254	803	
113	112.0	23.475	48.975	812	
114	113.0	23.259	48.614	805	
115	114.0	23.043	48.524	803	
116	115.0	22.899	47.938	794	
117	116.0	22.755	47.262	782	
118	117.0	22.611	48.749	809	
119	118.0	22.323	48.975	811	
120	119.0	22.107	48.839	809	
121	120.0	21.891	48.704	806	
122	121.0	21.675	48.344	800	
123	122.0	21.603	47.533	787	
124	123.0	21.459	49.110	814	
125	124.0	21.171	49.380	818	
126	125.0	20.955	48.839	808	
127	126.0	20.739	48.614	804	
128	127.0	20.595	48.254	799	
129	128.0	20.523	47.488	786	
130	129.0	20.451	46.992	778	
131	130.0	20.451	47.353	786	
132	131.0	20.307	48.479	804	
133	132.0	20.091	49.065	813	
134	133.0	19.875	48.749	806	
135	134.0	19.731	48.614	805	
136	135.0	19.587	48.344	800	
137	136.0	19.443	47.713	790	
138	137.0	19.371	47.172	780	
139	138.0	19.299	46.722	773	
140	139.0	19.299	46.361	768	
141	140.0	18.363	37.891	614	
142	141.0	17.355	31.403	512	
143	142.0	16.058	23.474	380	
144	143.0	15.410	18.518	302	
145	144.0	14.978	15.534	257	
146	145.0	14.690	13.787	229	
147	146.0	14.546	12.615	212	
148	147.0	14.402	11.759	198	
149	148.0	14.258	11.033	185	
150	149.0	14.186	10.492	178	
151	150.0	14.114	10.002	170	
152	151.0	14.042	9.597	133	

[illegible] 2.DAT

Number of Readings 215 No. Columns 4
Date Task Started 01/01/83 Time Task Started 18-03-51

	Time Secs 1	disp17 mm 2	LOAD18 KN 3	LOAD NOM 4
153	152.0	13.970	9.326	158
154	153.0	13.898	9.011	154
155	154.0	13.898	8.741	149
156	155.0	13.826	8.515	145
157	156.0	13.826	8.335	142
158	157.0	13.754	8.155	138
159	158.0	13.754	7.885	135
160	159.0	13.682	7.794	132
161	160.0	13.682	7.614	130
162	161.0	13.682	7.524	128
163	162.0	13.610	7.434	128
164	163.0	13.610	7.344	126
165	164.0	13.538	7.209	124
166	165.0	13.538	6.938	119
167	166.0	13.538	6.848	118
168	167.0	13.538	6.803	117
169	168.0	13.466	6.713	115
170	169.0	13.466	6.668	115
171	170.0	13.466	6.623	113
172	171.0	13.466	6.443	110
173	172.0	13.394	6.263	107
174	173.0	13.322	5.902	101
175	174.0	13.250	5.497	94
176	175.0	13.178	5.091	88
177	176.0	13.106	4.641	81
178	177.0	13.034	4.415	77
179	178.0	12.962	4.235	74
180	179.0	12.890	4.055	71
181	180.0	12.890	3.875	67
182	181.0	12.818	3.740	66
183	182.0	12.818	3.559	62
184	183.0	12.746	3.424	60
185	184.0	12.746	3.289	59
186	185.0	12.674	3.199	57
187	186.0	12.674	3.109	55
188	187.0	12.574	2.974	53
189	188.0	12.602	2.884	51
190	189.0	12.530	2.793	50
191	190.0	12.530	2.658	48
192	191.0	13.610	-0.225	-0
193	192.0	13.682	-0.180	2
194	193.0	13.682	-0.180	2
195	194.0	13.682	-0.180	3
196	195.0	13.682	-0.180	[illegible]
197	196.0	13.682	-0.180	3
198	197.0	13.682	-0.180	3
199	198.0	13.754	-0.180	4
200	199.0	13.754	-0.180	2
201	200.0	13.754	-0.180	3
202	201.0	13.754	-0.180	3
203	202.0	13.754	-0.180	3

TRIAXIAL TEST/TRIAX2-2.DAT

Number of Readings 215   No. Columns 4
Date Task Started 01/01/83   Time Task Started 18-03-51

	Time Secs 1	disp17 mm 2	LOAD18 KN 3	LOAD NOH 4
204	203.0	13.754	-0.180	3
205	204.0	13.754	-0.180	3
206	205.0	13.754	-0.180	2
207	206.0	13.682	-0.180	3
208	207.0	13.754	-0.180	2
209	208.0	13.754	-0.180	2
210	209.0	13.754	-0.180	3
211	210.0	13.754	-0.180	3
212	211.0	13.754	-0.180	2
213	212.0	13.754	-0.180	3
214	213.0	13.754	-0.180	3
215	214.0	13.754	-0.180	3

CALCULATION SHEET FOR TEST .... Triax 3

Peak axial load difference [kN] = 51.858 $\left.\vphantom{\begin{array}{c}a\\b\\c\end{array}}\right\}$ combination giving peak stress

Axial compression [mm] = 25.852

Cross - sectional area [m^2] = 0.05498

Stress difference, $\sigma_1 - \sigma_3$ [kN/m^2] = 943

Cell pressure, σ_3 [kN/m^2] = 380

Angle of friction, ϕ = **33.62°**

Axial load difference at 10% axial strain [kN] =

Stress difference, $\sigma_1 - \sigma_3$ [kN/m^2] =

Cell pressure, σ_3 [kN/m^2] =

Angle of friction, ϕ =

$$\text{Cross - sectional area} = \frac{\text{Sample volume}}{\text{Orig. height - axial comp.}}$$

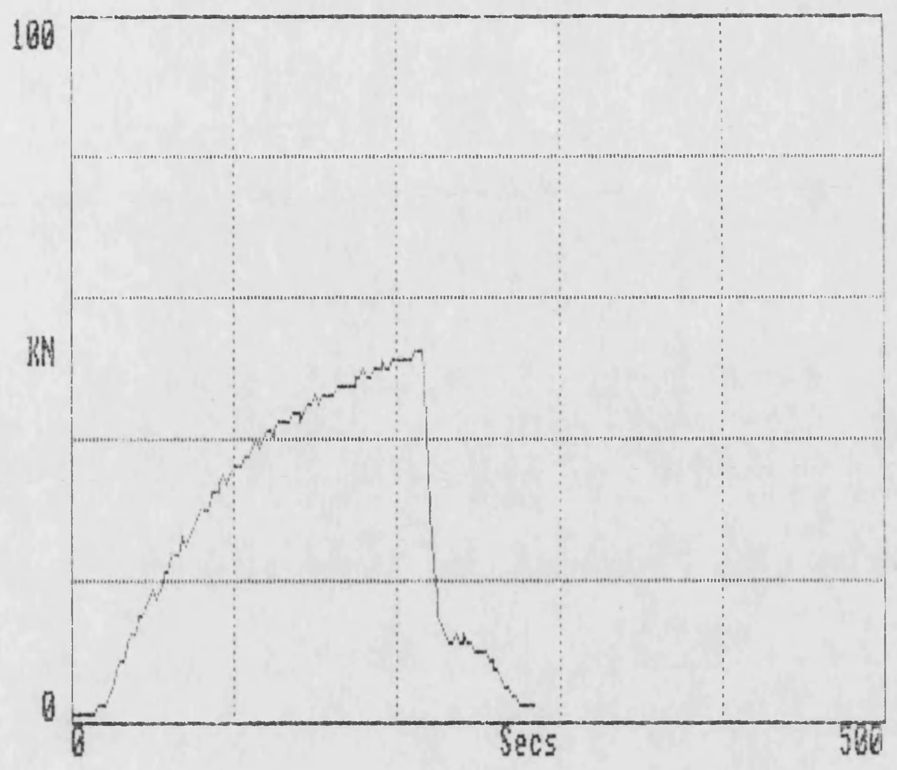
Angle of friction determined from; $\sin\phi = \dfrac{\sigma_1 - \sigma_3}{\sigma_1 + \sigma_3}$

Sample volume = 0.017 m^3,

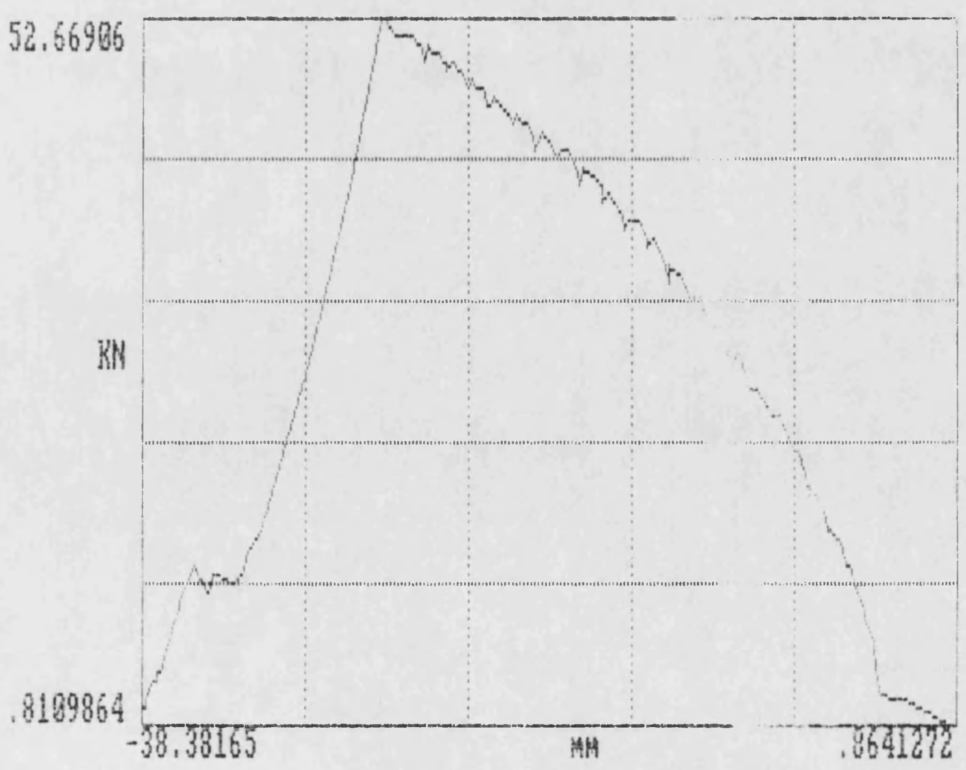
Original sample height = 335mm,

Cross - sectional area at 10% strain = 0.0563 m^2

LOAD18 v Time



LOAD18 v disp17



Number of Readings 142 No. Columns 4
Date Task Started 01/01/83 Time Task Started 00-16-54

	Time Secs 1	disp17 mm 2	LOAD18 KN 3	LOAD NON 4
0	0.0	0.864	0.811	16
1	2.0	0.864	0.811	16
2	4.0	0.864	0.811	17
3	6.0	0.864	0.811	16
4	8.0	0.864	0.811	16
5	10.0	0.864	0.811	16
6	12.0	0.864	0.811	16
7	14.0	0.864	0.811	16
8	16.0	-1.656	2.613	45
9	18.0	-2.160	2.974	51
10	20.0	-2.232	2.838	48
11	22.0	-2.808	3.379	56
12	24.0	-3.096	5.001	84
13	26.0	-3.096	4.731	79
14	28.0	-3.312	6.983	117
15	30.0	-3.601	8.876	146
16	32.0	-3.673	9.056	149
17	34.0	-4.105	11.489	188
18	36.0	-4.393	12.255	198
19	38.0	-4.537	12.165	200
20	40.0	-4.897	14.463	235
21	42.0	-5.185	15.319	248
22	44.0	-5.401	14.868	239
23	46.0	-5.545	16.535	267
24	48.0	-5.905	17.752	286
25	50.0	-6.193	18.247	292
26	52.0	-6.265	17.481	281
27	54.0	-6.409	19.058	307
28	56.0	-6.769	20.770	332
29	58.0	-7.057	20.635	331
30	60.0	-7.201	21.491	344
31	62.0	-7.633	23.248	372
32	64.0	-8.065	23.383	372
33	66.0	-8.209	24.104	386
34	68.0	-8.713	25.681	410
35	70.0	-9.073	25.591	408
36	72.0	-9.217	26.132	419
37	74.0	-9.649	28.024	446
38	76.0	-10.081	27.664	440
39	78.0	-10.153	28.339	454
40	80.0	-10.586	30.097	479
41	82.0	-11.018	30.052	478
42	84.0	-11.162	29.961	478
43	86.0	-11.594	32.394	516
44	88.0	-12.026	32.034	508
45	90.0	-12.170	32.530	519
46	92.0	-12.458	33.926	539
47	94.0	-12.962	34.422	546
48	96.0	-13.106	33.250	527
49	98.0	-13.322	35.233	560
50	100.0	-13.754	36.269	576

Number of Readings 142 No. Columns 4
Date Task Started 01/01/83 Time Task Started 00-16-54

	Time Secs 1	disp17 mm 2	LOAD18 KN 3	LOAD NON 4
51	102.0	-14.114	35.728	567
52	104.0	-14.186	36.179	574
53	106.0	-14.546	37.531	597
54	108.0	-14.978	38.026	604
55	110.0	-15.194	37.260	591
56	112.0	-15.410	38.657	616
57	114.0	-15.842	39.828	632
58	116.0	-16.202	39.063	619
59	118.0	-16.346	40.144	640
60	120.0	-16.706	41.225	654
61	122.0	-17.067	41.631	661
62	124.0	-17.283	40.324	640
63	126.0	-17.499	41.766	664
64	128.0	-17.859	42.802	680
65	130.0	-18.291	42.757	679
66	132.0	-18.435	42.397	675
67	134.0	-18.651	42.667	678
68	136.0	-18.795	43.433	690
69	138.0	-19.083	43.928	698
70	140.0	-19.371	43.613	692
71	142.0	-19.515	42.712	678
72	144.0	-19.587	44.244	704
73	146.0	-19.875	44.649	709
74	148.0	-20.091	45.010	716
75	150.0	-20.307	45.776	727
76	152.0	-20.523	44.604	707
77	154.0	-20.739	45.821	728
78	156.0	-21.027	46.497	739
79	158.0	-21.387	46.812	743
80	160.0	-21.603	46.497	738
81	162.0	-21.747	46.091	733
82	164.0	-21.963	47.217	750
83	166.0	-22.107	47.353	751
84	168.0	-22.323	47.803	760
85	170.0	-22.539	48.119	764
86	172.0	-22.683	47.308	750
87	174.0	-22.827	48.073	765
88	176.0	-22.971	48.479	771
89	178.0	-23.187	49.065	779
90	180.0	-23.475	49.380	785
91	182.0	-23.691	48.704	773
92	184.0	-23.836	49.245	783
93	186.0	-23.980	49.560	788
94	188.0	-24.196	50.056	794
95	190.0	-24.412	50.146	796
96	192.0	-24.700	50.777	806
97	194.0	-24.844	49.695	788
98	196.0	-24.988	50.597	804
99	198.0	-25.132	50.912	808
100	200.0	-25.420	51.408	815
101	202.0	-25.636	51.408	818

Number of Readings 142 No. Columns 4
Date Task Started 01/01/83 Time Task Started 00-16-54

	Time Secs 1	displ7 mm 2	LOAD18 KN 3	LOAD NON 4	
102	204.0	-25.852	51.137	811	
103	206.0	-25.924	51.272	815	
104	208.0	-26.140	51.588	818	
105	210.0	-26.284	51.678	820	
106	212.0	-26.428	52.128	828	
107	214.0	-26.716	52.669	836	* peak stress
108	216.0	-27.004	51.948	823	
109	218.0	-28.444	40.234	622	
110	220.0	-30.244	28.430	443	
111	222.0	-31.541	21.086	330	
112	224.0	-32.333	17.076	268	
113	226.0	-32.837	14.508	230	
114	228.0	-33.413	13.381	212	
115	230.0	-33.629	11.940	189	
116	232.0	-33.845	11.038	175	
117	234.0	-33.917	10.903	175	
118	236.0	-34.637	12.030	191	
119	238.0	-35.069	11.534	183	
120	240.0	-35.141	10.768	171	
121	242.0	-35.861	12.345	198	
122	244.0	-36.293	11.489	182	
123	246.0	-36.365	10.768	171	
124	248.0	-36.437	10.227	163	
125	250.0	-36.509	9.957	158	
126	252.0	-36.581	9.687	155	
127	254.0	-36.581	9.462	151	
128	256.0	-36.653	9.146	146	
129	258.0	-36.725	8.696	139	
130	260.0	-36.869	8.020	128	
131	262.0	-37.013	7.119	112	
132	264.0	-37.301	5.902	94	
133	266.0	-37.518	4.956	81	
134	268.0	-37.590	4.551	74	
135	270.0	-37.662	4.190	67	
136	272.0	-37.806	3.830	62	
137	274.0	-38.166	2.568	42	
138	276.0	-38.238	2.388	40	
139	278.0	-38.238	2.253	38	
140	280.0	-38.310	2.118	37	
141	282.0	-38.382	2.027	35	
142	284.0	-38.382	1.937	33	

CALCULATION SHEET FOR TEST .... Triax 4

Peak axial load difference [kN] = 55.688

Axial compression [mm] = 31.18

} combination giving peak stress

Cross - sectional area [m^2] = 0.056

Stress difference, $\sigma_1 - \sigma_3$ [kN/m^2] = 995

Cell pressure, σ_3 [kN/m^2] = 400

Angle of friction, ϕ = **33.66°**

Axial load difference at 10% axial strain [kN] =

Stress difference, $\sigma_1 - \sigma_3$ [kN/m^2] =

Cell pressure, σ_3 [kN/m^2] =

Angle of friction, ϕ =

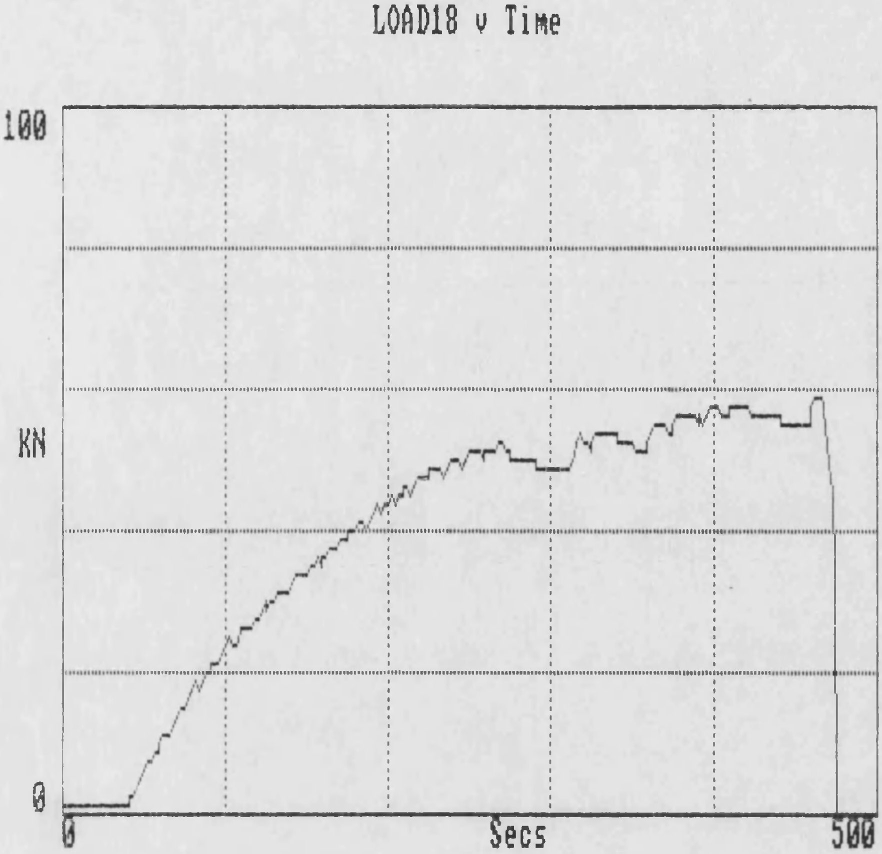
$$\text{Cross - sectional area} = \frac{\text{Sample volume}}{\text{Orig. height - axial comp.}}$$

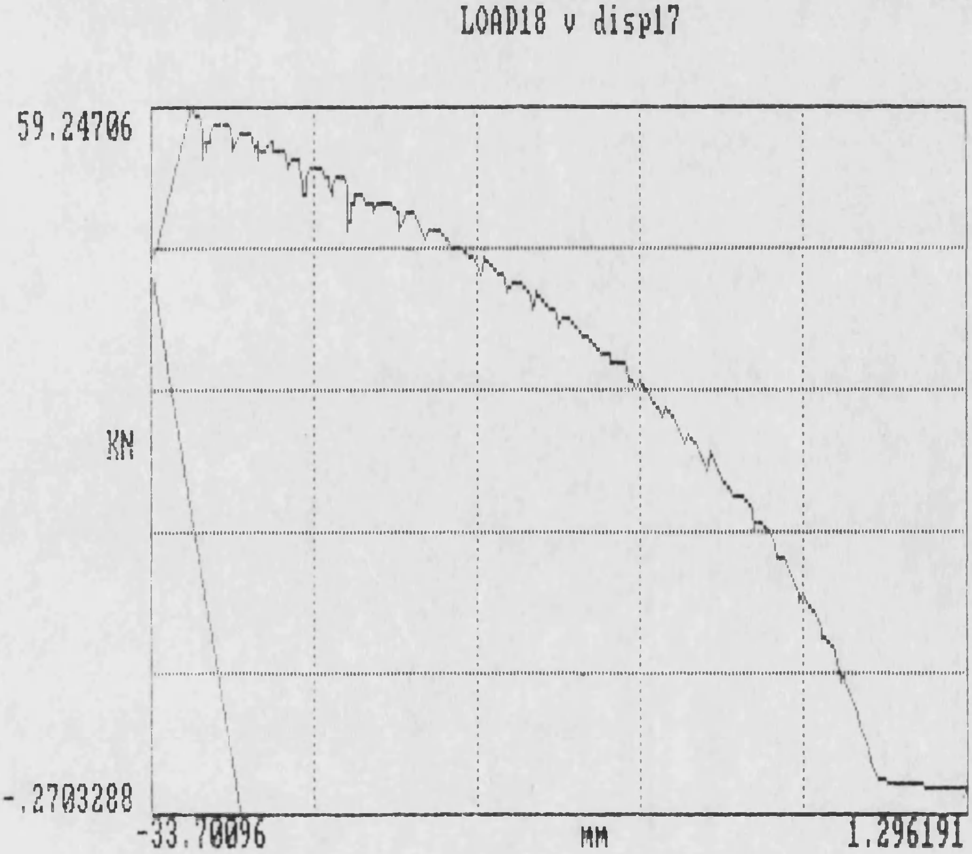
Angle of friction determined from; $\sin\phi = \dfrac{\sigma_1 - \sigma_3}{\sigma_1 + \sigma_3}$

Sample volume = 0.017 m^3,

Original sample height = 335mm,

Cross - sectional area at 10% strain = 0.0563 m^2


LOAD18 v Time
100
KN
0
0
Secs
500


LOAD18 v disp17
59.24706
KN
-.2703288
-33.70096
mm
1.296191

TRIAXIAL TEST/TRIAX4.DAT

Number of Readings 249 No. Columns 4
Date Task Started 01/01/83 Time Task Started 00-24-21

	Time Secs 1	disp17 mm 2	LOAD18 KN 3	LOAD NON 4
0	0.0	1.224	1.622	26
1	2.0	1.224	1.622	26
2	4.0	1.224	1.622	24
3	6.0	1.224	1.622	24
4	8.0	1.224	1.577	25
5	10.0	1.224	1.622	26
6	12.0	1.224	1.622	26
7	14.0	1.224	1.622	26
8	16.0	1.224	1.622	25
9	18.0	1.224	1.622	26
10	20.0	1.224	1.622	25
11	22.0	1.224	1.622	25
12	24.0	1.224	1.622	26
13	26.0	1.224	1.622	25
14	28.0	1.224	1.622	24
15	30.0	1.224	1.622	25
16	32.0	1.224	1.622	25
17	34.0	1.224	1.622	25
18	36.0	1.224	1.622	25
19	38.0	1.224	1.622	25
20	40.0	1.296	1.622	24
21	42.0	0.720	1.937	31
22	44.0	-2.592	3.064	48
23	46.0	-2.736	3.785	55
24	48.0	-2.808	4.460	66
25	50.0	-3.024	5.767	84
26	52.0	-3.240	7.389	107
27	54.0	-3.384	7.479	105
28	56.0	-3.457	8.290	119
29	58.0	-3.601	9.326	132
30	60.0	-3.745	10.092	143
31	62.0	-3.889	10.723	152
32	64.0	-4.033	11.399	159
33	66.0	-4.105	11.174	157
34	68.0	-4.249	12.525	176
35	70.0	-4.465	13.877	196
36	72.0	-4.753	14.913	211
37	74.0	-4.897	14.733	206
38	76.0	-4.969	15.544	218
39	78.0	-5.257	16.625	234
40	80.0	-5.473	17.436	245
41	82.0	-5.689	18.382	259
42	84.0	-5.833	17.932	251
43	86.0	-5.905	18.427	257
44	88.0	-6.121	19.734	277
45	90.0	-6.337	20.545	287
46	92.0	-6.553	20.996	293
47	94.0	-6.769	21.401	298
48	96.0	-6.841	21.491	300
49	98.0	-6.985	22.753	318
50	100.0	-7.201	23.699	331

TRIAXIAL TEST/TRIAX4.DAT

Number of Readings 249 No. Columns 4
Date Task Started 01/01/83 Time Task Started 00-24-21

	Time Secs 1	disp17 mm 2	LOAD18 KN 3	LOAD NON 4
51	102.0	-7.489	24.600	344
52	104.0	-7.705	24.014	333
53	106.0	-7.705	23.879	333
54	108.0	-7.921	25.636	357
55	110.0	-8.209	26.177	364
56	112.0	-8.425	26.808	373
57	114.0	-8.713	26.627	370
58	116.0	-8.785	26.808	374
59	118.0	-8.929	27.619	384
60	120.0	-9.145	28.069	390
61	122.0	-9.361	29.060	405
62	124.0	-9.649	29.871	415
63	126.0	-9.793	28.565	397
64	128.0	-9.937	29.646	412
65	130.0	-10.153	30.457	423
66	132.0	-10.370	31.088	433
67	134.0	-10.586	31.583	440
68	136.0	-10.730	31.223	432
69	138.0	-10.802	31.268	435
70	140.0	-10.946	32.079	446
71	142.0	-11.090	32.710	455
72	144.0	-11.306	33.386	464
73	146.0	-11.594	33.971	471
74	148.0	-11.810	33.205	461
75	150.0	-11.954	34.016	474
76	152.0	-12.170	34.827	485
77	154.0	-12.386	35.323	492
78	156.0	-12.674	35.909	500
79	158.0	-12.890	35.458	491
80	160.0	-13.034	35.999	500
81	162.0	-13.178	36.449	507
82	164.0	-13.394	37.305	517
83	166.0	-13.682	37.801	526
84	168.0	-13.970	37.305	517
85	170.0	-14.042	38.161	530
86	172.0	-14.330	38.747	538
87	174.0	-14.618	39.243	545
88	176.0	-14.906	39.964	554
89	178.0	-15.050	39.603	552
90	180.0	-15.410	40.549	564
91	182.0	-15.770	41.045	570
92	184.0	-16.058	41.631	578
93	186.0	-16.202	40.459	560
94	188.0	-16.346	41.811	581
95	190.0	-16.562	42.171	586
96	192.0	-16.850	42.937	597
97	194.0	-17.139	43.388	602
98	196.0	-17.283	42.036	583
99	198.0	-17.427	43.433	603
100	200.0	-17.787	44.334	616
101	202.0	-18.147	44.739	620

TRIAXIAL TEST/TRIAX4.DAT

Number of Readings 249 No. Columns 4
Date Task Started 01/01/83 Time Task Started 00-24-21

	Time Secs 1	displ7 mm 2	LOAD18 KN 3	LOAD NON 4
102	204.0	-18.435	43.973	609
103	206.0	-18.579	44.875	622
104	208.0	-18.795	45.190	626
105	210.0	-19.083	46.046	639
106	212.0	-19.443	46.497	645
107	214.0	-19.587	45.145	625
108	216.0	-19.803	46.406	643
109	218.0	-20.019	46.947	650
110	220.0	-20.307	47.713	662
111	222.0	-20.667	47.308	654
112	224.0	-20.739	47.217	655
113	226.0	-20.955	48.209	667
114	228.0	-21.315	48.659	673
115	230.0	-21.603	48.794	677
116	232.0	-21.819	48.614	673
117	234.0	-21.891	48.073	667
118	236.0	-22.107	49.020	678
119	238.0	-22.251	49.425	685
120	240.0	-22.467	50.011	692
121	242.0	-22.683	50.101	694
122	244.0	-22.899	49.876	691
123	246.0	-22.971	49.065	679
124	248.0	-23.115	50.506	700
125	250.0	-23.331	50.912	704
126	252.0	-23.619	51.047	706
127	254.0	-23.836	51.002	707
128	256.0	-23.980	51.227	710
129	258.0	-24.124	50.281	695
130	260.0	-24.196	51.137	708
131	262.0	-24.340	51.182	709
132	264.0	-24.484	51.362	711
133	266.0	-24.556	51.543	713
134	268.0	-24.700	51.993	721
135	270.0	-24.916	52.038	721
136	272.0	-24.988	51.272	709
137	274.0	-25.060	50.777	704
138	276.0	-25.132	50.461	699
139	278.0	-25.132	50.236	695
140	280.0	-25.132	50.011	692
141	282.0	-25.132	49.876	690
142	284.0	-25.132	49.741	689
143	286.0	-25.132	49.605	688
144	288.0	-25.204	49.515	685
145	290.0	-25.204	49.425	685
146	292.0	-25.204	49.335	682
147	294.0	-25.204	49.245	681
148	296.0	-25.204	49.200	680
149	298.0	-25.204	49.110	681
150	300.0	-25.204	49.065	679
151	302.0	-25.276	49.020	680
152	304.0	-25.276	48.975	676

TRIAXIAL TEST/TRIAX4.DAT

Number of Readings 249 No. Columns 4
Date Task Started 01/01/83 Time Task Started 00-24-21

	Time Secs 1	displ7 mm 2	LOAD18 KN 3	LOAD NON 4
153	306.0	-25.276	48.884	679
154	308.0	-25.276	48.839	678
155	310.0	-25.276	48.794	677
156	312.0	-25.276	48.794	676
157	314.0	-25.276	50.056	696
158	316.0	-25.348	52.264	726
159	318.0	-25.492	53.255	737
160	320.0	-25.708	53.029	733
161	322.0	-25.852	52.534	727
162	324.0	-25.924	51.858	718
163	326.0	-25.996	52.714	731
164	328.0	-26.140	53.300	738
165	330.0	-26.284	53.525	742
166	332.0	-26.428	53.840	746
167	334.0	-26.572	53.840	746
168	336.0	-26.716	54.111	749
169	338.0	-26.932	54.246	752
170	340.0	-27.004	53.390	739
171	342.0	-27.004	52.894	732
172	344.0	-27.076	52.534	727
173	346.0	-27.076	52.264	724
174	348.0	-27.076	52.083	721
175	350.0	-27.148	51.948	719
176	352.0	-27.148	51.768	718
177	354.0	-27.148	51.678	716
178	356.0	-27.148	51.543	715
179	358.0	-27.148	51.453	714
180	360.0	-27.220	52.714	732
181	362.0	-27.292	53.795	745
182	364.0	-27.292	54.426	754
183	366.0	-27.436	54.697	757
184	368.0	-27.580	54.922	761
185	370.0	-27.724	54.967	761
186	372.0	-27.868	54.246	751
187	374.0	-27.868	53.795	745
188	376.0	-28.012	55.282	766
189	378.0	-28.156	55.688	770
190	380.0	-28.372	55.643	770
191	382.0	-28.516	56.048	775
192	384.0	-28.732	55.823	773
193	386.0	-28.876	55.823	773
194	388.0	-29.020	55.778	771
195	390.0	-29.020	55.057	763
196	392.0	-29.164	56.319	780
197	394.0	-29.308	55.508	768
198	396.0	-29.452	56.724	786
199	398.0	-29.596	57.039	789
200	400.0	-29.740	57.084	790
201	402.0	-29.956	57.310	793 * Peak
202	404.0	-30.100	56.454	781
203	406.0	-30.172	55.823	773

Number of Readings 249   No. Columns 4
Date Task Started 01/01/83   Time Task Started 00-24-21

	Time	displ7	LOAD18	LOAD
	Secs	mm	KN	NON
	1	2	3	4
204	408.0	-30.172	56.273	781
205	410.0	-30.316	57.490	795
206	412.0	-30.532	57.445	794
207	414.0	-30.677	57.625	798
208	416.0	-30.821	57.895	802
209	418.0	-30.965	57.805	800
210	420.0	-31.109	57.220	792
211	422.0	-31.181	56.679	785
212	424.0	-31.181	56.319	779
213	426.0	-31.253	56.048	777
214	428.0	-31.253	55.868	774
215	430.0	-31.325	56.589	784
216	432.0	-31.325	56.364	780
217	434.0	-31.325	56.183	777
218	436.0	-31.397	56.003	775
219	438.0	-31.397	55.868	772
220	440.0	-31.397	55.733	771
221	442.0	-31.397	55.598	770
222	444.0	-31.469	55.508	768
223	446.0	-31.469	55.417	767
224	448.0	-31.469	55.327	766
225	450.0	-31.469	55.237	765
226	452.0	-31.469	55.192	765
227	454.0	-31.469	55.102	762
228	456.0	-31.469	55.057	763
229	458.0	-31.469	55.012	761
230	460.0	-31.541	56.949	788
231	462.0	-31.613	58.211	807
232	464.0	-31.757	58.751	813
233	466.0	-31.901	59.247	821
234	468.0	-32.765	53.615	736
235	470.0	-33.413	48.209	665
236	472.0	-33.701	45.550	630
237	474.0	-29.884	-0.090	-3
238	476.0	-22.539	-0.270	1
239	478.0	-22.539	-0.270	1
240	480.0	-22.539	-0.270	0
241	482.0	-22.539	-0.225	3
242	484.0	-28.516	-0.225	3
243	486.0	-30.532	-0.225	2
244	488.0	-30.532	-0.225	2
245	490.0	-30.532	-0.225	3
246	492.0	-30.532	-0.225	3
247	494.0	-30.460	-0.225	3
248	496.0	-30.460	-0.225	3
249	498.0	-30.460	-0.225	1

CALCULATION SHEET FOR TEST .... Triax 5

Peak axial load difference [kN] = 63.572 } combination giving peak stress

Axial compression [mm] = 35.72

Cross - sectional area [m^2] = 0.0568

Stress difference, $\sigma_1 - \sigma_3$ [kN/m^2] = 1119

Cell pressure, σ_3 [kN/m^2] = 400

Angle of friction, ϕ = **35.67°**

Axial load difference at 10% axial strain [kN] = 59.70

Stress difference, $\sigma_1 - \sigma_3$ [kN/m^2] = 1060

Cell pressure, σ_3 [kN/m^2] = 400

Angle of friction, ϕ = **34.74°**

$$\text{Cross - sectional area} = \frac{\text{Sample volume}}{\text{Orig. height - axial comp.}}$$

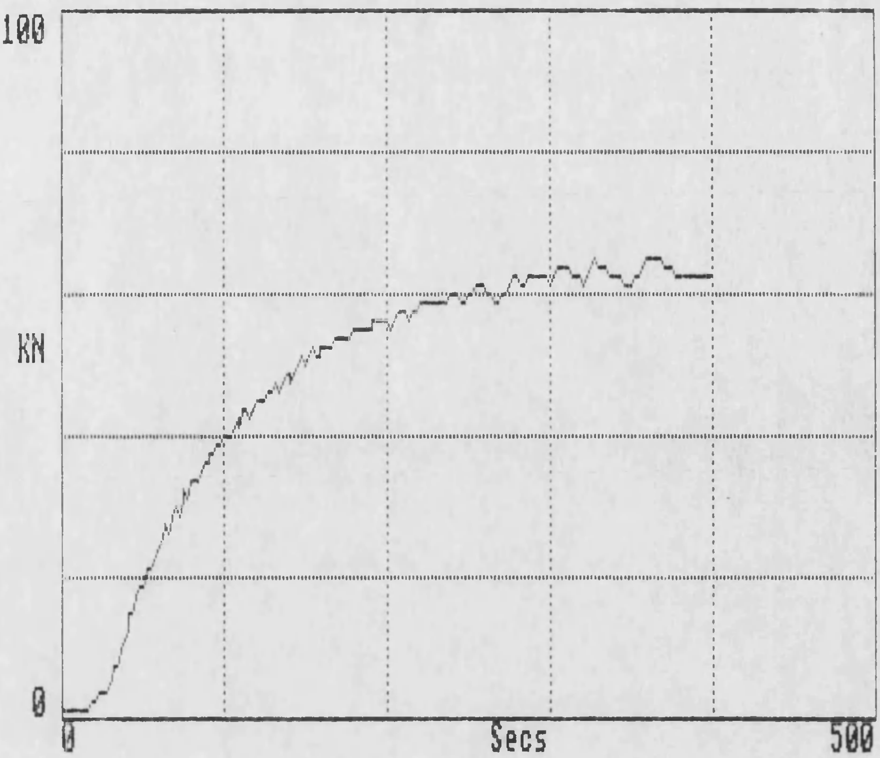
$$\text{Angle of friction determined from; } \sin\phi = \frac{\sigma_1 - \sigma_3}{\sigma_1 + \sigma_3}$$

Sample volume = 0.017 m^3,

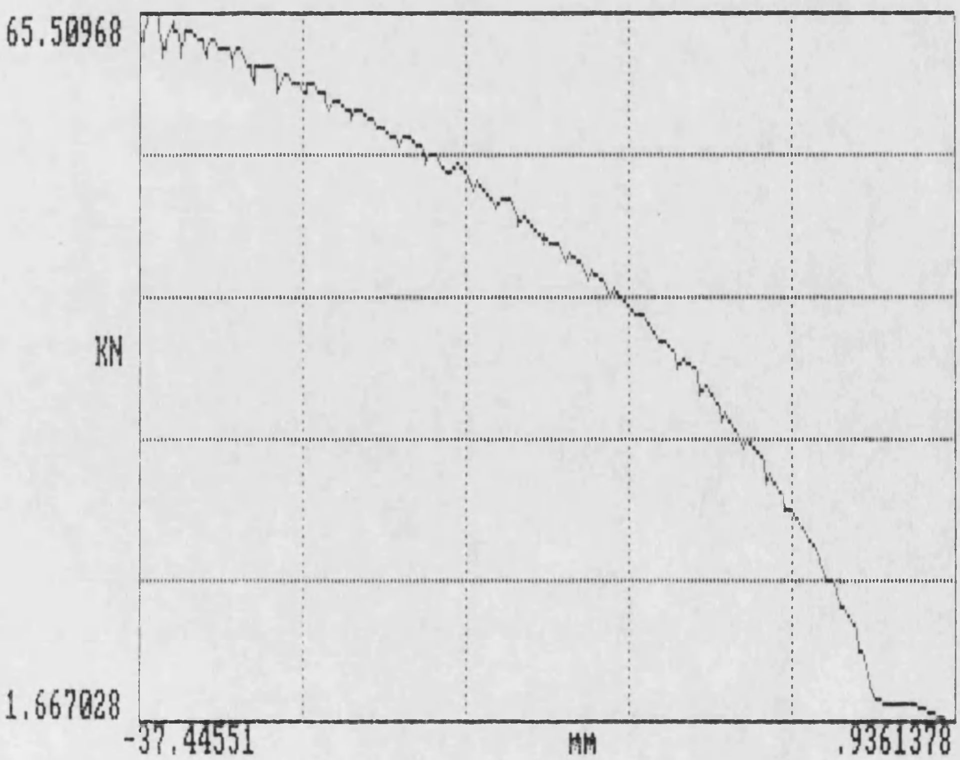
Original sample height = 335mm,

Cross - sectional area at 10% strain = 0.0563 m^2

LOAD18 v Time



LOAD18 v disp17



TRIAXIAL TEST/TRIAX5.DAT

==

Number of Readings 200 No. Columns 4

Date Task Started 01/01/83 Time Task Started 00-21-21

==

	Time Secs 1	displ7 mm 2	LOAD18 KN 3	LOAD NON 4
0	0.0	0.936	1.667	12
1	2.0	0.936	1.667	15
2	4.0	0.936	1.667	15
3	6.0	0.936	1.667	13
4	8.0	0.936	1.667	12
5	10.0	0.936	1.667	13
6	12.0	0.936	1.667	15
7	14.0	0.936	1.667	15
8	16.0	0.936	1.667	12
9	18.0	0.864	1.982	15
10	20.0	-0.936	2.884	24
11	22.0	-1.512	3.379	28
12	24.0	-1.656	3.154	25
13	26.0	-2.232	3.649	30
14	28.0	-2.952	3.920	33
15	30.0	-3.096	5.091	42
16	32.0	-3.457	7.930	66
17	34.0	-3.529	7.704	66
18	36.0	-3.817	10.272	87
19	38.0	-4.321	11.849	99
20	40.0	-4.465	12.255	100
21	42.0	-4.897	14.823	126
22	44.0	-5.257	14.778	123
23	46.0	-5.617	17.256	143
24	48.0	-6.121	18.382	151
25	50.0	-6.265	18.878	159
26	52.0	-6.697	21.176	178
27	54.0	-7.057	20.860	170
28	56.0	-7.273	22.302	185
29	58.0	-7.705	24.149	201
30	60.0	-7.993	23.519	195
31	62.0	-8.209	25.501	210
32	64.0	-8.785	27.078	225
33	66.0	-9.073	26.087	216
34	68.0	-9.289	28.385	234
35	70.0	-9.793	29.556	243
36	72.0	-10.009	28.700	238
37	74.0	-10.226	30.682	257
38	76.0	-10.730	31.989	264
39	78.0	-11.090	30.998	257
40	80.0	-11.306	33.205	277
41	82.0	-11.738	34.287	285
42	84.0	-12.098	33.521	275
43	86.0	-12.314	35.188	293
44	88.0	-12.674	36.269	304
45	90.0	-13.034	36.044	297
46	92.0	-13.250	37.035	307
47	94.0	-13.754	37.981	317
48	96.0	-14.114	38.206	318
49	98.0	-14.330	38.927	325
50	100.0	-14.762	40.009	334

TRIAXIAL TEST/TRIAX5.DAT

==

Number of Readings 200 No. Columns 4

Date Task Started 01/01/83 Time Task Started 00-21-21

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	Time Secs 1	displ7 mm 2	LOAD18 KN 3	LOAD NON 4
51	102.0	-15.194	40.414	336
52	104.0	-15.338	40.324	335
53	106.0	-15.698	41.541	346
54	108.0	-16.130	42.352	354
55	110.0	-16.346	41.270	342
56	112.0	-16.706	43.343	361
57	114.0	-17.139	43.838	366
58	116.0	-17.427	42.892	355
59	118.0	-17.571	43.793	366
60	120.0	-17.787	44.514	370
61	122.0	-18.075	45.145	376
62	124.0	-18.363	45.595	380
63	126.0	-18.507	44.604	371
64	128.0	-18.651	45.956	381
65	130.0	-18.939	46.722	391
66	132.0	-19.299	47.308	393
67	134.0	-19.587	46.542	386
68	136.0	-19.659	47.308	395
69	138.0	-19.947	48.479	402
70	140.0	-20.379	48.839	407
71	142.0	-20.667	47.893	400
72	144.0	-20.883	48.930	406
73	146.0	-21.171	49.876	413
74	148.0	-21.531	50.687	423
75	150.0	-21.819	49.425	409
76	152.0	-22.035	50.957	424
77	154.0	-22.395	52.038	433
78	156.0	-22.827	51.408	426
79	158.0	-23.043	51.408	429
80	160.0	-23.259	52.309	435
81	162.0	-23.547	52.759	439
82	164.0	-23.836	53.029	441
83	166.0	-24.052	52.219	432
84	168.0	-24.268	53.165	443
85	170.0	-24.412	53.750	447
86	172.0	-24.772	54.066	449
87	174.0	-24.988	54.066	452
88	176.0	-25.204	53.615	445
89	178.0	-25.276	53.210	444
90	180.0	-25.420	54.426	453
91	182.0	-25.636	54.471	452
92	184.0	-25.852	55.282	460
93	186.0	-26.068	55.462	460
94	188.0	-26.284	55.192	460
95	190.0	-26.356	54.742	455
96	192.0	-26.500	55.823	464
97	194.0	-26.644	56.003	468
98	196.0	-26.932	56.409	469
99	198.0	-27.148	56.544	471
100	200.0	-27.364	56.679	470
101	202.0	-27.508	55.553	462

TRIAXIAL TEST/TRIAX5.DAT

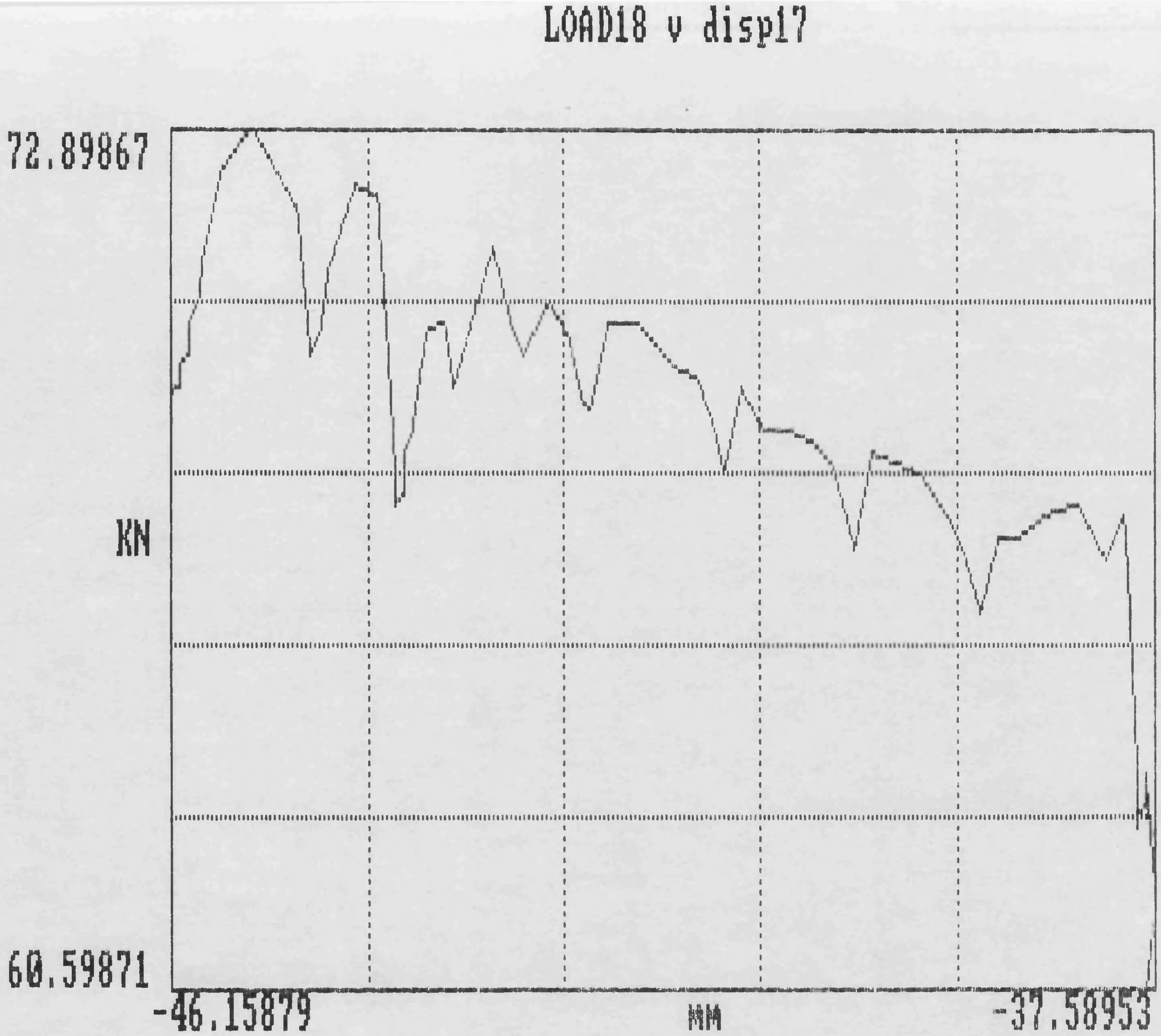
Number of Readings 200 No. Columns 4
Date Task Started 01/01/83 Time Task Started 00-21-21

	Time Secs 1	disp17 mm 2	LOAD18 KN 3	LOAD NON 4	
102	204.0	-27.580	56.634	472	
103	206.0	-27.724	57.039	473	
104	208.0	-27.940	57.715	484	
105	210.0	-28.228	57.805	480	
106	212.0	-28.444	57.715	481	
107	214.0	-28.588	56.769	470	
108	216.0	-28.660	57.175	477	
109	218.0	-28.804	57.940	482	
110	220.0	-28.948	58.211	484	
111	222.0	-29.092	58.661	489	
112	224.0	-29.308	58.797	487	
113	226.0	-29.524	58.977	490	
114	228.0	-29.668	58.346	485	
115	230.0	-29.740	58.571	488	
116	232.0	-29.884	58.887	489	
117	234.0	-29.956	59.022	492	
118	236.0	-30.100	59.202	491	
119	238.0	-30.244	59.472	494	
120	240.0	-30.460	59.698	496	
121	242.0	-30.605	59.698	495	
122	244.0	-30.749	59.517	495	
123	246.0	-30.893	58.751	487	
124	248.0	-30.965	58.616	488	
125	250.0	-31.037	59.653	496	
126	252.0	-31.109	60.464	504	
127	254.0	-31.325	60.734	503	
128	256.0	-31.469	60.734	506	
129	258.0	-31.685	60.734	504	
130	260.0	-31.829	60.689	505	
131	262.0	-31.973	60.328	501	
132	264.0	-32.045	59.653	497	
133	266.0	-32.117	59.157	492	
134	268.0	-32.117	58.842	490	
135	270.0	-32.189	59.833	497	
136	272.0	-32.261	60.599	505	
137	274.0	-32.333	60.959	505	
138	276.0	-32.477	61.815	515	
139	278.0	-32.693	61.995	513	
140	280.0	-32.909	62.131	518	
141	282.0	-33.053	61.365	509	10% strain
142	284.0	-33.125	60.689	504	
143	286.0	-33.197	61.950	514	
144	288.0	-33.341	62.446	520	
145	290.0	-33.557	62.401	518	
146	292.0	-33.701	62.671	521	
147	294.0	-33.917	62.851	522	
148	296.0	-34.133	62.987	526	
149	298.0	-34.277	62.040	513	
150	300.0	-34.349	61.365	509	
151	302.0	-34.493	62.446	518	
152	304.0	-34.565	63.167	525	

TRIAXIAL TEST/TRIAX5.DAT

Number of Readings 200 No. Columns 4
Date Task Started 01/01/83 Time Task Started 00-21-21

	Time Secs 1	disp17 mm 2	LOAD18 KN 3	LOAD NON 4	
153	306.0	-34.709	63.302	524	
154	308.0	-34.925	63.753	530	
155	310.0	-35.069	63.527	526	
156	312.0	-35.285	63.933	531	
157	314.0	-35.429	63.077	523	
158	316.0	-35.501	62.446	517	
159	318.0	-35.501	62.040	517	
160	320.0	-35.573	61.725	512	
161	322.0	-35.573	62.671	521	
162	324.0	-35.645	63.572	527	
163	326.0	-35.789	63.978	532	
164	328.0	-35.933	64.428	535	
165	330.0	-36.005	63.978	532	
166	332.0	-36.077	63.888	529	
167	334.0	-36.149	63.302	526	
168	336.0	-36.221	62.897	522	
169	338.0	-36.221	62.536	517	
170	340.0	-36.293	62.311	517	
171	342.0	-36.293	62.086	514	
172	344.0	-36.365	61.950	515	
173	346.0	-36.365	61.770	513	
174	348.0	-36.365	61.680	513	
175	350.0	-36.365	61.545	511	
176	352.0	-36.365	61.950	515	
177	354.0	-36.437	62.626	521	
178	356.0	-36.509	64.023	532	
179	358.0	-36.509	64.744	538	
180	360.0	-36.653	65.239	541	
181	362.0	-36.797	65.375	542	peak
182	364.0	-36.869	65.375	544	
183	366.0	-37.013	65.510	543	
184	368.0	-37.157	64.609	538	
185	370.0	-37.229	64.113	535	
186	372.0	-37.229	63.753	528	
187	374.0	-37.301	63.437	527	
188	376.0	-37.301	63.257	524	
189	378.0	-37.301	63.077	524	
190	380.0	-37.374	62.942	521	
191	382.0	-37.374	62.806	522	
192	384.0	-37.374	62.671	521	
193	386.0	-37.374	62.581	517	
194	388.0	-37.374	62.491	519	
195	390.0	-37.446	62.401	517	
196	392.0	-37.446	62.266	516	
197	394.0	-37.446	62.221	515	
198	396.0	-37.446	62.176	514	
199	398.0	-37.446	62.086	515	
200	400.0	-37.446	62.040	516	


LOAD18 v disp17
72.89867
KN
60.59871
-46.15879
MM
-37.58953

Number of Readings 87 No. Columns 4
Date Task Started 01/01/83 Time Task Started 00-30-00

	Time Secs 1	disp17 mm 2	LOAD18 KN 3	LOAD NON 4
0	0.0	-37.590	60.689	507
1	2.0	-37.590	60.689	502
2	4.0	-37.590	60.644	504
3	6.0	-37.590	60.644	503
4	8.0	-37.590	60.644	499
5	10.0	-37.662	60.599	501
6	12.0	-37.590	61.860	514
7	14.0	-37.662	63.572	525
8	16.0	-37.662	63.617	526
9	18.0	-37.662	63.572	525
10	20.0	-37.662	63.482	525
11	22.0	-37.662	63.437	525
12	24.0	-37.662	63.392	525
13	26.0	-37.662	63.347	524
14	28.0	-37.662	63.257	523
15	30.0	-37.662	63.212	525
16	32.0	-37.662	63.167	523
17	34.0	-37.734	63.122	522
18	36.0	-37.734	63.077	521
19	38.0	-37.734	63.032	520
20	40.0	-37.734	62.987	522
21	42.0	-37.734	62.942	523
22	44.0	-37.734	63.482	525
23	46.0	-37.806	66.411	550
24	48.0	-37.878	67.312	555
25	50.0	-38.022	66.726	552
26	52.0	-38.238	67.537	561
27	54.0	-38.526	67.402	558
28	56.0	-38.742	67.042	556
29	58.0	-38.958	67.132	559
30	60.0	-39.102	65.960	546
31	62.0	-39.246	66.951	556
32	64.0	-39.390	67.357	557
33	66.0	-39.606	68.033	563
34	68.0	-39.822	68.123	562
35	70.0	-40.038	68.258	567
36	72.0	-40.182	66.951	554
37	74.0	-40.398	68.078	564
38	76.0	-40.542	68.393	567
39	78.0	-40.758	68.664	568
40	80.0	-40.974	68.618	567
41	82.0	-41.190	69.249	571
42	84.0	-41.334	67.988	562
43	86.0	-41.406	68.664	569
44	88.0	-41.550	69.339	576
45	90.0	-41.766	69.520	575
46	92.0	-42.054	70.060	579
47	94.0	-42.342	70.060	579
48	96.0	-42.486	68.844	568
49	98.0	-42.558	68.979	570
50	100.0	-42.702	69.925	578

TRIAXIAL TEST/TRIAX5-2.DAT

Number of Readings 87 No. Columns 4
Date Task Started 01/01/83 Time Task Started 00-30-00

	Time Secs 1	disp17 mm 2	LOAD18 KN 3	LOAD NON 4
51	102.0	-42.846	70.421	583
52	104.0	-43.062	69.745	577
53	106.0	-43.206	70.105	579
54	108.0	-43.350	71.142	587
55	110.0	-43.566	70.195	578
56	112.0	-43.710	69.249	571
57	114.0	-43.782	70.150	578
58	116.0	-43.926	69.970	577
59	118.0	-43.998	69.249	574
60	120.0	-44.070	68.799	570
61	122.0	-44.070	68.528	567
62	124.0	-44.143	68.258	564
63	126.0	-44.143	68.033	563
64	128.0	-44.143	67.898	560
65	130.0	-44.143	67.717	557
66	132.0	-44.143	67.627	558
67	134.0	-44.215	67.492	557
68	136.0	-44.215	67.762	559
69	138.0	-44.287	69.925	577
70	140.0	-44.359	71.953	598
71	142.0	-44.575	72.133	597
72	144.0	-44.791	70.826	586
73	146.0	-44.863	69.970	578
74	148.0	-44.935	69.745	576
75	150.0	-45.079	71.772	593
76	152.0	-45.223	72.223	595
77	154.0	-45.439	72.899	601
78	156.0	-45.727	72.223	595
79	158.0	-45.871	71.051	585
80	160.0	-45.943	70.466	581
81	162.0	-46.015	70.060	579
82	164.0	-46.015	69.745	575
83	166.0	-46.087	69.520	574
84	168.0	-46.087	69.294	572
85	170.0	-46.087	69.159	572
86	172.0	-46.159	69.069	572
87	174.0	-46.159	68.889	570

CALCULATION SHEET FOR TEST .... Triax 6

Peak axial load difference [kN] = 48.98

Axial compression [mm] = 40.04

} combination giving peak stress

Cross - sectional area [m^2] = 0.0576

Stress difference, $\sigma_1 - \sigma_3$ [kN/m^2] = 850

Cell pressure, σ_3 [kN/m^2] = 200

Angle of friction, ϕ = **42.83°**

Axial load difference at 10% axial strain [kN] = 45.06

Stress difference, $\sigma_1 - \sigma_3$ [kN/m^2] = 800

Cell pressure, σ_3 [kN/m^2] = 200

Angle of friction, ϕ = **41.81°**

$$\text{Cross - sectional area} = \frac{\text{Sample volume}}{\text{Orig. height - axial comp.}}$$

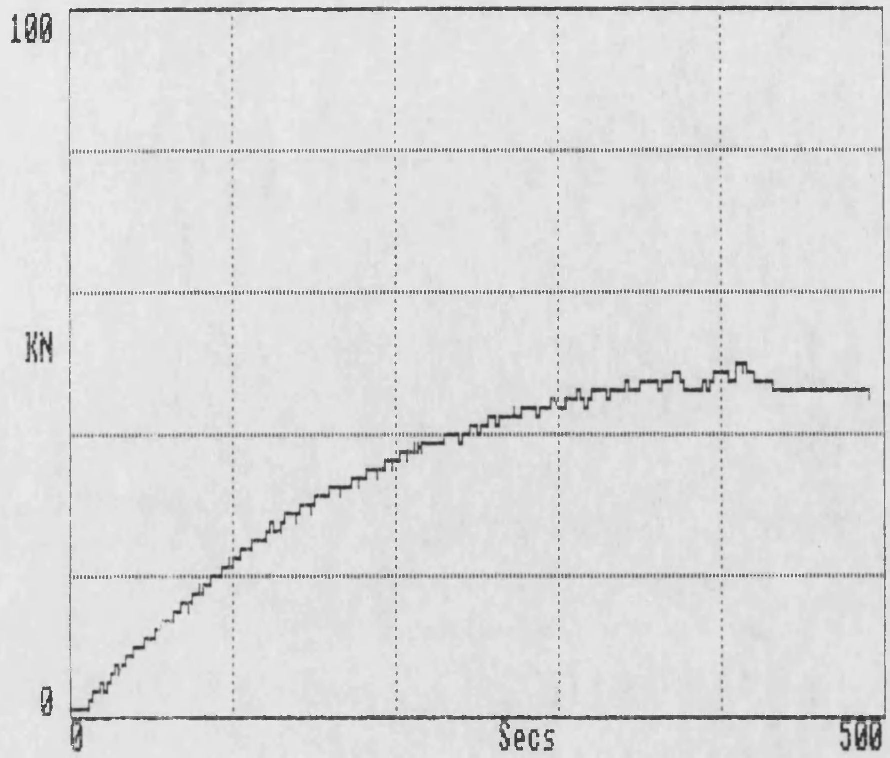
Angle of friction determined from; $\sin \phi = \dfrac{\sigma_1 - \sigma_3}{\sigma_1 + \sigma_3}$

Sample volume = 0.017 m^3,

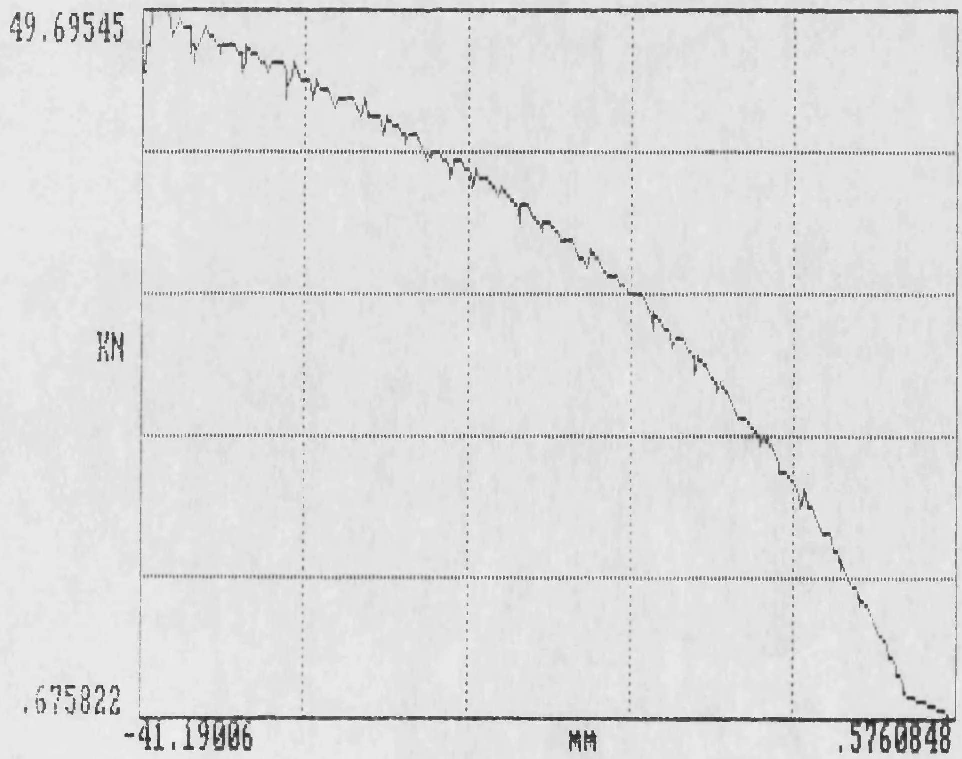
Original sample height = 335mm,

Cross - sectional area at 10% strain = 0.0563 m^2

LOAD18 v Time



LOAD18 v disp17



TRIAXIAL TEST/TRIAX6.DAT

Number of Readings 331 No. Columns 4
Date Task Started 01/01/83 Time Task Started 00-46-44

	Time Secs 1	disp17 mm 2	LOAD18 KN 3	LOAD NON 4
0	0.0	0.576	0.721	13
1	2.0	0.576	0.721	12
2	4.0	0.576	0.721	13
3	6.0	0.576	0.676	13
4	8.0	0.576	0.721	13
5	10.0	0.576	0.721	12
6	12.0	0.576	0.721	13
7	14.0	0.576	0.721	13
8	16.0	0.576	0.721	13
9	18.0	0.576	0.721	13
10	20.0	0.072	1.577	29
11	22.0	-2.016	2.478	43
12	24.0	-2.160	3.064	52
13	26.0	-2.304	3.559	60
14	28.0	-2.448	3.965	65
15	30.0	-2.520	4.280	71
16	32.0	-2.664	4.776	81
17	34.0	-2.808	5.181	87
18	36.0	-3.024	6.082	102
19	38.0	-3.384	6.983	116
20	40.0	-3.457	6.848	113
21	42.0	-3.673	7.659	128
22	44.0	-3.961	8.470	140
23	46.0	-4.321	9.236	152
24	48.0	-4.393	8.876	145
25	50.0	-4.537	9.687	161
26	52.0	-4.753	10.137	166
27	54.0	-4.897	10.453	172
28	56.0	-5.113	11.174	183
29	58.0	-5.329	11.444	187
30	60.0	-5.401	11.309	185
31	62.0	-5.545	12.255	201
32	64.0	-5.689	12.525	206
33	66.0	-5.833	13.336	219
34	68.0	-6.121	13.832	226
35	70.0	-6.265	13.652	223
36	72.0	-6.409	14.282	234
37	74.0	-6.625	14.913	244
38	76.0	-6.841	15.138	249
39	78.0	-6.985	15.589	255
40	80.0	-7.273	16.355	267
41	82.0	-7.417	15.589	255
42	84.0	-7.561	16.670	273
43	86.0	-7.777	17.301	284
44	88.0	-8.137	17.797	291
45	90.0	-8.497	17.707	289
46	92.0	-8.569	18.427	302
47	94.0	-8.785	18.923	309
48	96.0	-8.929	19.374	317
49	98.0	-9.217	20.139	330
50	100.0	-9.433	19.599	319

TRIAXIAL TEST/TRIAX6.DAT

Number of Readings 331 No. Columns 4
Date Task Started 01/01/83 Time Task Started 00-46-44

	Time Secs 1	disp17 mm 2	LOAD18 KN 3	LOAD NON 4
51	102.0	-9.577	20.365	333
52	104.0	-9.793	21.041	344
53	106.0	-10.153	21.807	357
54	108.0	-10.586	21.716	353
55	110.0	-10.730	22.122	362
56	112.0	-10.946	22.933	375
57	114.0	-11.162	23.248	380
58	116.0	-11.522	23.834	389
59	118.0	-11.738	23.248	378
60	120.0	-11.810	24.059	393
61	122.0	-12.098	24.645	402
62	124.0	-12.314	25.186	412
63	126.0	-12.674	25.546	416
64	128.0	-12.818	24.825	404
65	130.0	-12.962	26.087	425
66	132.0	-13.250	26.357	430
67	134.0	-13.538	26.988	442
68	136.0	-13.898	26.853	437
69	138.0	-13.970	26.402	431
70	140.0	-14.186	27.619	451
71	142.0	-14.330	27.754	453
72	144.0	-14.618	28.520	466
73	146.0	-14.906	28.880	472
74	148.0	-15.050	27.934	456
75	150.0	-15.122	28.835	472
76	152.0	-15.338	29.421	481
77	154.0	-15.626	30.097	493
78	156.0	-16.058	29.871	486
79	158.0	-16.202	29.961	491
80	160.0	-16.418	30.637	501
81	162.0	-16.634	30.998	508
82	164.0	-16.922	31.268	511
83	166.0	-17.211	31.178	509
84	168.0	-17.355	31.133	509
85	170.0	-17.571	31.944	523
86	172.0	-17.859	32.394	531
87	174.0	-18.219	32.935	539
88	176.0	-18.435	31.764	518
89	178.0	-18.579	32.710	536
90	180.0	-18.723	32.800	536
91	182.0	-18.939	33.386	546
92	184.0	-19.227	33.791	554
93	186.0	-19.515	33.566	548
94	188.0	-19.659	33.566	549
95	190.0	-19.803	33.881	555
96	192.0	-19.947	34.377	563
97	194.0	-20.307	35.053	574
98	196.0	-20.595	35.278	578
99	198.0	-20.739	34.152	559
100	200.0	-20.955	35.278	577
101	202.0	-21.171	35.458	580

[illegible]

Number of Readings 331 No. Columns 4
Date Task Started 01/01/83 Time Task Started 00-46-44

	Time Secs 1	displ7 mm 2	LOAD18 KN 3	LOAD NON 4
102	204.0	-21.387	36.089	591
103	206.0	-21.819	36.269	594
104	208.0	-21.891	35.233	576
105	210.0	-22.107	36.314	594
106	212.0	-22.323	36.810	603
107	214.0	-22.683	37.305	610
108	216.0	-23.043	36.765	602
109	218.0	-23.187	37.395	613
110	220.0	-23.475	37.891	622
111	222.0	-23.836	38.116	625
112	224.0	-24.124	38.387	629
113	226.0	-24.268	37.305	611
114	228.0	-24.412	38.702	634
115	230.0	-24.700	38.927	638
116	232.0	-24.916	39.153	642
117	234.0	-25.204	39.108	641
118	236.0	-25.348	38.297	627
119	238.0	-25.420	38.927	640
120	240.0	-25.636	39.378	646
121	242.0	-25.780	39.558	650
122	244.0	-26.068	39.874	654
123	246.0	-26.284	40.144	659
124	248.0	-26.500	39.423	647
125	250.0	-26.572	39.333	647
126	252.0	-26.716	40.144	660
127	254.0	-26.932	40.324	662
128	256.0	-27.148	41.090	676
129	258.0	-27.436	41.315	679
130	260.0	-27.652	40.504	664
131	262.0	-27.796	41.135	677
132	264.0	-27.940	41.405	681
133	266.0	-28.156	41.856	688
134	268.0	-28.372	41.946	688
135	270.0	-28.660	42.397	695
136	272.0	-28.804	41.315	679
137	274.0	-28.948	42.261	696
138	276.0	-29.164	42.306	695
139	278.0	-29.380	42.532	699
140	280.0	-29.596	42.622	700
141	282.0	-29.884	43.388	713
142	284.0	-30.028	42.171	693
143	286.0	-30.172	42.892	706
144	288.0	-30.316	43.298	712
145	290.0	-30.605	43.748	719
146	292.0	-30.821	43.433	714
147	294.0	-31.109	43.748	718
148	296.0	-31.253	42.937	705
149	298.0	-31.325	43.027	708
150	300.0	-31.469	43.748	720
151	302.0	-31.613	43.928	721
152	304.0	-31.829	44.289	728

TRIAXIAL TEST/TRIAX6.DAT

Number of Readings 331 No. Columns 4
Date Task Started 01/01/83 Time Task Started 00-46-44

	Time Secs 1	displ7 mm 2	LOAD18 KN 3	LOAD NON 4
153	306.0	-32.045	44.469	731
154	308.0	-32.261	44.694	735
155	310.0	-32.405	43.613	716
156	312.0	-32.477	43.343	714
157	314.0	-32.621	44.649	734
158	316.0	-32.837	44.649	734
159	318.0	-32.981	44.875	738
160	320.0	-33.197	45.280	745
161	322.0	-33.413	45.776	753
162	324.0	-33.629	44.694	734
163	326.0	-33.701	44.109	726
164	328.0	-33.701	43.793	721
165	330.0	-33.773	45.190	744
166	332.0	-33.989	45.956	755
167	334.0	-34.205	46.226	760
168	336.0	-34.421	45.911	755
169	338.0	-34.637	46.091	758
170	340.0	-34.709	45.100	743
171	342.0	-34.853	46.001	756
172	344.0	-34.997	46.001	756
173	346.0	-35.141	46.181	760
174	348.0	-35.357	46.722	769
175	350.0	-35.501	46.767	770
176	352.0	-35.789	46.947	771
177	354.0	-35.933	46.136	757
178	356.0	-36.005	45.641	749
179	358.0	-36.077	46.542	766
180	360.0	-36.221	46.812	770
181	362.0	-36.365	47.082	774
182	364.0	-36.581	47.353	779
183	366.0	-36.797	47.443	780
184	368.0	-36.941	47.533	781
185	370.0	-37.157	46.992	772
186	372.0	-37.157	46.361	762
187	374.0	-37.229	46.947	772
188	376.0	-37.374	47.443	780
189	378.0	-37.518	47.803	786
190	380.0	-37.734	48.073	791
191	382.0	-37.950	48.254	794
192	384.0	-38.238	48.073	790
193	386.0	-38.382	47.127	773
194	388.0	-38.454	46.587	767
195	390.0	-38.454	46.271	761
196	392.0	-38.526	46.091	758
197	394.0	-38.526	45.911	755
198	396.0	-38.526	46.091	759
199	398.0	-38.598	47.172	776
200	400.0	-38.670	47.037	774
201	402.0	-38.670	46.722	769
202	404.0	-38.742	47.037	774
203	406.0	-38.814	48.479	797

10% strain

TRIAXIAL TEST/TRIAX6.DAT

Number of Readings 331 No. Columns 4
Date Task Started 01/01/83 Time Task Started 00-46-44

	Time Secs 1	displ7 mm 2	LOAD18 KN 3	LOAD NON 4	
204	408.0	-38.958	48.479	797	
205	410.0	-39.174	48.344	795	
206	412.0	-39.318	48.930	805	
207	414.0	-39.534	48.524	797	
208	416.0	-39.606	47.668	783	
209	418.0	-39.678	47.578	783	
210	420.0	-39.894	49.605	818	
211	422.0	-40.182	49.425	813	
212	424.0	-40.398	49.650	816	
213	426.0	-40.614	49.695	818	peak
214	428.0	-40.758	48.569	798	
215	430.0	-40.830	48.028	790	
216	432.0	-40.830	47.668	783	
217	434.0	-40.902	47.443	780	
218	436.0	-40.902	47.262	777	
219	438.0	-40.902	47.082	775	
220	440.0	-40.974	46.992	772	
221	442.0	-40.974	46.857	771	
222	444.0	-40.974	46.767	769	
223	446.0	-40.974	46.677	768	
224	448.0	-40.974	46.587	766	
225	450.0	-40.974	46.497	766	
226	452.0	-41.046	46.452	764	
227	454.0	-41.046	46.361	763	
228	456.0	-41.046	46.316	762	
229	458.0	-41.046	46.271	761	
230	460.0	-41.046	46.226	759	
231	462.0	-41.046	46.181	760	
232	464.0	-41.046	46.136	759	
233	466.0	-41.046	46.091	759	
234	468.0	-41.046	46.046	758	
235	470.0	-41.046	46.046	758	
236	472.0	-41.046	46.001	757	
237	474.0	-41.046	45.956	756	
238	476.0	-41.046	45.911	755	
239	478.0	-41.046	45.911	756	
240	480.0	-41.046	45.866	755	
241	482.0	-41.046	45.821	755	
242	484.0	-41.046	45.821	754	
243	486.0	-41.046	45.776	753	
244	488.0	-41.118	45.776	752	
245	490.0	-41.046	45.731	752	
246	492.0	-41.118	45.686	751	
247	494.0	-41.118	45.686	752	
248	496.0	-41.118	45.686	751	
249	498.0	-41.118	45.641	750	
250	500.0	-41.118	45.641	750	
251	502.0	-41.046	45.595	751	
252	504.0	-41.118	45.595	750	
253	506.0	-41.118	45.550	749	
254	508.0	-41.118	45.550	749	

TRIAXIAL TEST/TRIAX6.DAT

Number of Readings 331 No. Columns 4
Date Task Started 01/01/83 Time Task Started 00-46-44

	Time Secs 1	displ7 mm 2	LOAD18 KN 3	LOAD NON 4
255	510.0	-41.118	45.505	749
256	512.0	-41.118	45.505	748
257	514.0	-41.118	45.460	749
258	516.0	-41.118	45.460	749
259	518.0	-41.118	45.415	747
260	520.0	-41.118	45.460	747
261	522.0	-41.118	45.415	748
262	524.0	-41.118	45.415	747
263	526.0	-41.118	45.370	747
264	528.0	-41.118	45.370	746
265	530.0	-41.118	45.370	746
266	532.0	-41.118	45.325	746
267	534.0	-41.118	45.325	746
268	536.0	-41.118	45.325	746
269	538.0	-41.118	45.280	746
270	540.0	-41.118	45.280	745
271	542.0	-41.118	45.280	745
272	544.0	-41.118	45.280	745
273	546.0	-41.118	45.235	745
274	548.0	-41.118	45.235	744
275	550.0	-41.118	45.190	743
276	552.0	-41.118	45.190	744
277	554.0	-41.118	45.190	743
278	556.0	-41.118	45.190	743
279	558.0	-41.118	45.190	743
280	560.0	-41.118	45.145	743
281	562.0	-41.118	45.145	742
[illegible]	564.0	-41.118	45.145	743
283	566.0	-41.118	45.100	742
284	568.0	-41.190	45.100	743
285	570.0	-41.118	45.100	741
286	572.0	-41.118	45.100	742
287	574.0	-41.190	45.100	742
288	576.0	-41.118	45.055	742
289	578.0	-41.118	45.055	741
290	580.0	-41.118	45.055	741
291	582.0	-41.118	45.010	741
292	584.0	-41.118	45.010	740
293	586.0	-41.190	45.010	741
294	588.0	-41.190	45.010	740
295	590.0	-41.190	45.010	740
296	592.0	-41.190	44.965	740
297	594.0	-41.190	44.965	740
298	596.0	-41.190	44.965	740
299	598.0	-41.190	44.920	740
300	600.0	-41.190	44.920	740
301	602.0	-41.190	44.920	739
302	604.0	-41.190	44.920	740
303	606.0	-41.190	44.920	739
304	608.0	-41.190	44.920	739
305	610.0	-41.190	44.875	739

Number of Readings 331 No. Columns 4
Date Task Started 01/01/83 Time Task Started 00-46-44

	Time Secs 1	disp17 mm 2	LOAD18 KN 3	LOAD NON 4
306	612.0	-41.190	44.875	738
307	614.0	-41.190	44.875	739
308	616.0	-41.190	44.830	738
309	618.0	-41.190	44.830	738
310	620.0	-41.190	44.830	738
311	622.0	-41.190	44.830	738
312	624.0	-41.190	44.830	738
313	626.0	-41.190	44.830	738
314	628.0	-41.190	44.784	737
315	630.0	-41.190	44.784	738
316	632.0	-41.190	44.784	736
317	634.0	-41.190	44.784	736
318	636.0	-41.190	44.784	737
319	638.0	-41.190	44.739	737
320	640.0	-41.190	44.739	735
321	642.0	-41.190	44.739	736
322	644.0	-41.190	44.739	736
323	646.0	-41.190	44.739	736
324	648.0	-41.190	44.739	736
325	650.0	-41.190	44.739	736
326	652.0	-41.190	44.694	735
327	654.0	-41.190	44.694	734
328	656.0	-41.190	44.694	735
329	658.0	-41.190	44.694	735
330	660.0	-41.190	44.649	734
331	662.0	-41.190	44.649	735

CALCULATION SHEET FOR TEST .... Triax 7

Peak axial load difference [kN] = 69.83 — combination giving peak stress

Axial compression [mm] = 58.0 — combination giving peak stress

Cross - sectional area [m^2] = 0.0614

Stress difference, $\sigma_1 - \sigma_3$ [kN/m^2] = 1138

Cell pressure, σ_3 [kN/m^2] = 300

Angle of friction, ϕ = **40.89°**

Axial load difference at 10% axial strain [kN] = 54.98

Stress difference, $\sigma_1 - \sigma_3$ [kN/m^2] = 976

Cell pressure, σ_3 [kN/m^2] = 300

Angle of friction, ϕ = **38.28°**

$$\text{Cross - sectional area} = \frac{\text{Sample volume}}{\text{Orig. height - axial comp.}}$$

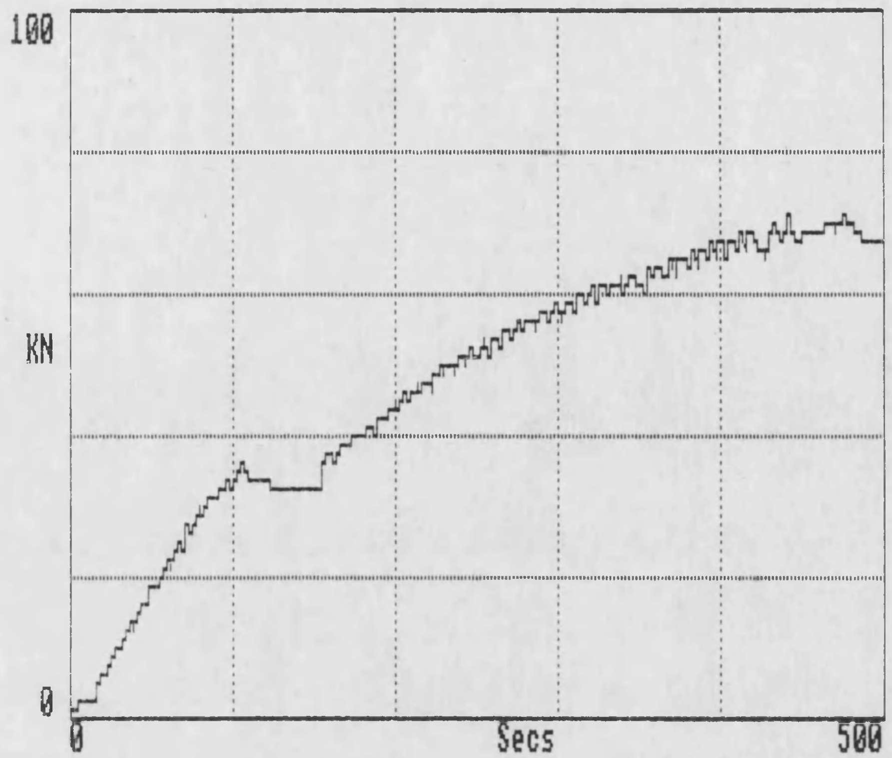
Angle of friction determined from; $\sin \phi = \dfrac{\sigma_1 - \sigma_3}{\sigma_1 + \sigma_3}$

Sample volume = 0.017 m^3,

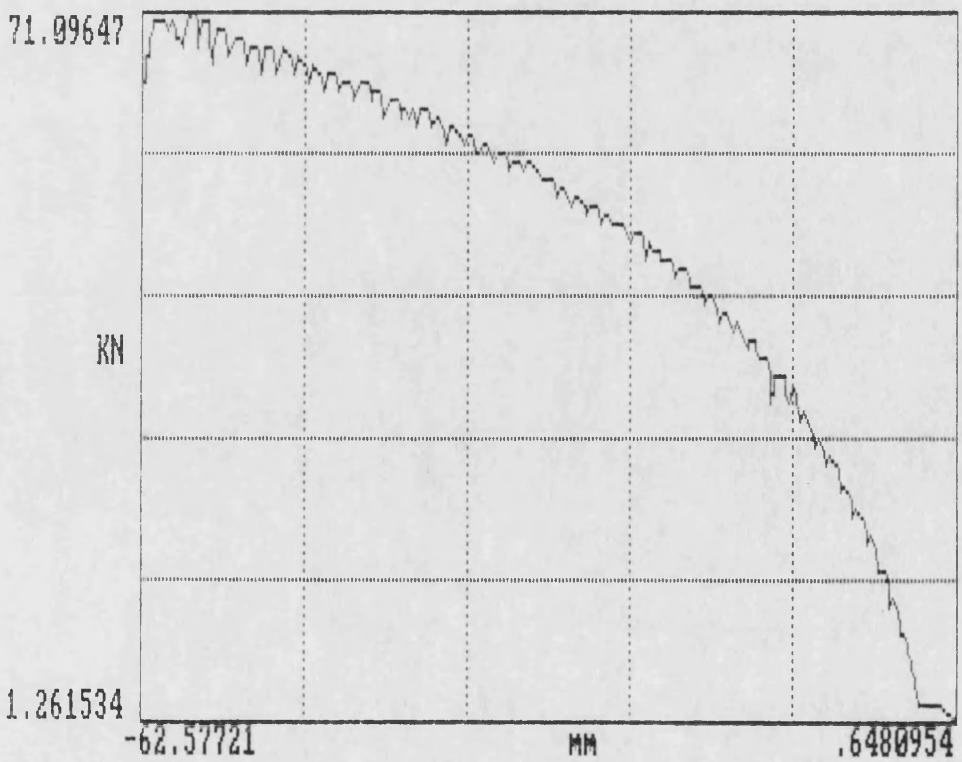
Original sample height = 335mm,

Cross - sectional area at 10% strain = 0.0563 m^2

LOAD18 v Time



LOAD18 v disp17



Number of Readings 400 No. Columns 4

Date Task Started 01/01/83 Time Task Started 00-47-59

	Time Secs 1	disp17 mm 2	LOAD18 KN 3	LOAD NON 4
0	0.0	0.648	1.262	23
1	2.0	0.648	1.307	23
2	4.0	0.648	1.307	22
3	6.0	0.648	1.307	22
4	8.0	0.648	1.307	22
5	10.0	0.648	1.307	22
6	12.0	0.648	1.307	21
7	14.0	0.648	1.577	27
8	16.0	-0.576	2.613	45
9	18.0	-1.224	2.658	43
10	20.0	-1.440	2.703	45
11	22.0	-1.872	2.793	46
12	24.0	-2.016	2.703	43
13	26.0	-2.160	2.974	49
14	28.0	-2.376	4.505	76
15	30.0	-2.520	5.902	96
16	32.0	-2.664	6.353	102
17	34.0	-2.736	6.983	113
18	36.0	-2.952	8.065	130
19	38.0	-3.168	9.011	146
20	40.0	-3.457	10.002	162
21	42.0	-3.529	9.642	156
22	44.0	-3.673	10.948	179
23	46.0	-3.961	12.300	200
24	48.0	-4.177	13.336	215
25	50.0	-4.393	12.886	207
26	52.0	-4.537	14.237	231
27	54.0	-4.825	15.679	253
28	56.0	-5.185	16.445	264
29	58.0	-5.329	16.130	260
30	60.0	-5.617	18.337	296
31	62.0	-6.049	19.374	310
32	64.0	-6.265	18.788	301
33	66.0	-6.337	19.824	319
34	68.0	-6.553	21.086	337
35	70.0	-6.985	22.167	354
36	72.0	-7.273	21.401	341
37	74.0	-7.417	22.708	364
38	76.0	-7.705	24.059	387
39	78.0	-8.137	25.005	400
40	80.0	-8.209	24.239	387
41	82.0	-8.641	26.718	427
42	84.0	-9.145	27.258	436
43	86.0	-9.289	26.492	424
44	88.0	-9.577	28.520	457
45	90.0	-10.009	29.376	469
46	92.0	-10.298	28.745	459
47	94.0	-10.442	29.916	479
48	96.0	-10.730	31.088	497
49	98.0	-11.090	31.809	508
50	100.0	-11.306	31.043	495

TRIAXIAL TEST/TRIAX7.DAT

Number of Readings 400 No. Columns 4

Date Task Started 01/01/83 Time Task Started 00-47-59

	Time Secs 1	disp17 mm 2	LOAD18 KN 3	LOAD NON 4
51	102.0	-11.378	31.358	502
52	104.0	-11.594	32.530	520
53	106.0	-11.810	33.296	534
54	108.0	-12.098	34.242	548
55	110.0	-12.386	32.935	526
56	112.0	-12.458	33.926	545
57	114.0	-12.674	34.963	562
58	116.0	-13.106	35.638	571
59	118.0	-13.466	35.008	559
60	120.0	-13.538	34.332	549
61	122.0	-13.538	33.971	544
62	124.0	-13.538	33.746	541
63	126.0	-13.610	33.521	537
64	128.0	-13.610	33.386	535
65	130.0	-13.610	33.296	533
66	132.0	-13.610	33.205	532
67	134.0	-13.610	33.115	531
68	136.0	-13.610	33.025	528
69	138.0	-13.610	32.980	528
70	140.0	-13.682	32.890	528
71	142.0	-13.682	32.845	527
72	144.0	-13.682	32.800	525
73	146.0	-13.682	32.710	525
74	148.0	-13.682	32.665	524
75	150.0	-13.682	32.620	524
76	152.0	-13.682	32.620	522
77	154.0	-13.682	32.530	522
78	156.0	-13.682	32.530	522
79	158.0	-13.682	32.485	521
80	160.0	-13.682	32.439	520
81	162.0	-13.682	32.394	520
82	164.0	-13.682	33.070	532
83	166.0	-13.754	35.323	567
84	168.0	-13.898	36.900	592
85	170.0	-14.114	37.350	598
86	172.0	-14.402	37.305	597
87	174.0	-14.546	37.125	595
88	176.0	-14.762	37.891	608
89	178.0	-14.978	38.477	617
90	180.0	-15.338	38.792	623
91	182.0	-15.554	38.161	612
92	184.0	-15.698	39.153	628
93	186.0	-15.986	39.783	638
94	188.0	-16.274	40.279	647
95	190.0	-16.634	39.738	637
96	192.0	-16.778	40.504	650
97	194.0	-17.067	41.225	663
98	196.0	-17.571	41.811	671
99	198.0	-17.787	40.594	651
100	200.0	-18.003	41.901	673
101	202.0	-18.363	42.982	691

Number of Readings 400 No. Columns 4
Date Task Started 01/01/83 Time Task Started 00-47-59

	Time Secs 1	disp17 mm 2	LOAD18 KN 3	LOAD NON 4	
102	204.0	-18.723	43.027	691	
103	206.0	-18.939	42.306	680	
104	208.0	-19.227	43.793	704	
105	210.0	-19.515	44.199	710	
106	212.0	-19.947	44.199	709	
107	214.0	-20.163	44.784	721	
108	216.0	-20.451	45.460	731	
109	218.0	-20.883	45.776	736	
110	220.0	-21.171	44.694	717	
111	222.0	-21.387	46.497	749	
112	224.0	-21.891	46.812	753	
113	226.0	-22.251	46.406	745	
114	228.0	-22.467	47.217	761	
115	230.0	-22.899	47.893	770	
116	232.0	-23.331	48.073	774	
117	234.0	-23.547	46.767	752	
118	236.0	-23.836	49.020	789	
119	238.0	-24.340	49.290	794	
120	240.0	-24.628	48.344	776	
121	242.0	-24.844	49.425	796	
122	244.0	-25.276	50.416	811	
123	246.0	-25.780	50.011	805	
124	248.0	-25.996	50.461	813	
125	250.0	-26.428	51.182	826	
126	252.0	-26.788	51.092	823	
127	254.0	-27.004	50.011	804	
128	256.0	-27.364	51.993	837	
129	258.0	-27.796	51.858	835	
130	260.0	-28.084	51.362	827	
131	262.0	-28.228	51.723	834	
132	264.0	-28.588	52.939	853	
133	266.0	-29.020	53.120	856	
134	268.0	-29.380	51.993	837	
135	270.0	-29.524	53.029	856	
136	272.0	-29.884	54.021	872	
137	274.0	-30.244	54.021	870	
138	276.0	-30.532	52.804	850	
139	278.0	-30.821	54.651	882	
140	280.0	-31.253	54.922	885	
141	282.0	-31.613	54.291	874	
142	284.0	-31.829	55.057	889	
143	286.0	-32.261	55.913	902	
144	288.0	-32.693	56.003	903	
145	290.0	-32.909	55.012	888	10% strain
146	292.0	-33.269	56.319	909	
147	294.0	-33.701	56.228	907	
148	296.0	-34.061	55.643	896	
149	298.0	-34.205	56.048	906	
150	300.0	-34.493	56.949	921	
151	302.0	-34.853	57.175	923	
152	304.0	-35.213	56.679	913	

TRIAXIAL TEST/TRIAX7.DAT

Number of Readings 400 No. Columns 4
Date Task Started 01/01/83 Time Task Started 00-47-59

	Time Secs 1	disp17 mm 2	LOAD18 KN 3	LOAD NON 4
153	306.0	-35.429	57.355	927
154	308.0	-35.789	57.670	932
155	310.0	-36.077	58.166	939
156	312.0	-36.437	57.084	921
157	314.0	-36.653	57.535	931
158	316.0	-36.941	58.526	945
159	318.0	-37.374	59.022	953
160	320.0	-37.662	57.760	932
161	322.0	-37.806	59.247	959
162	324.0	-38.310	59.878	967
163	326.0	-38.742	59.562	962
164	328.0	-38.958	58.256	942
165	330.0	-39.174	60.058	972
166	332.0	-39.606	60.824	983
167	334.0	-40.038	59.472	961
168	336.0	-40.182	60.148	973
169	338.0	-40.542	61.455	994
170	340.0	-41.046	61.320	991
171	342.0	-41.262	59.607	963
172	344.0	-41.550	61.545	996
173	346.0	-41.838	61.004	984
174	348.0	-42.054	61.815	1001
175	350.0	-42.414	61.320	990
176	352.0	-42.558	60.689	982
177	354.0	-42.846	62.266	1007
178	356.0	-43.206	62.401	1009
179	358.0	-43.566	61.770	997
180	360.0	-43.710	61.365	993
181	362.0	-43.854	60.734	982
182	364.0	-43.926	60.193	974
183	366.0	-44.215	63.617	1031
184	368.0	-44.647	63.257	1022
185	370.0	-44.863	62.040	1004
186	372.0	-45.151	63.753	1031
187	374.0	-45.727	64.203	1039
188	376.0	-46.087	62.491	1010
189	378.0	-46.231	62.987	1021
190	380.0	-46.591	64.383	1042
191	382.0	-47.023	64.473	1043
192	384.0	-47.239	63.077	1021
193	386.0	-47.671	65.194	1055
194	388.0	-48.175	64.699	1046
195	390.0	-48.463	63.572	1027
196	392.0	-48.679	65.329	1060
197	394.0	-49.255	65.780	1065
198	396.0	-49.615	64.473	1041
199	398.0	-49.903	66.050	1071
200	400.0	-50.479	66.681	1079
201	402.0	-50.911	64.879	1049
202	404.0	-51.128	66.726	1082
203	406.0	-51.776	67.357	1091

Number of Readings 400 No. Columns 4
Date Task Started 01/01/83 Time Task Started 00-47-59

	Time Secs 1	displ7 mm 2	LOAD18 KN 3	LOAD NON 4	
204	408.0	-52.136	65.149	1053	
205	410.0	-52.496	67.447	1094	
206	412.0	-53.144	67.357	1090	
207	414.0	-53.432	65.284	1058	
208	416.0	-53.792	67.672	1097	
209	418.0	-54.296	67.717	1097	
210	420.0	-54.656	65.960	1067	
211	422.0	-54.872	68.078	1104	
212	424.0	-55.520	68.799	1115	
213	426.0	-55.880	66.546	1077	
214	428.0	-56.240	68.934	1118	
215	430.0	-56.744	69.114	1119	
216	432.0	-57.032	67.402	1090	
217	434.0	-57.176	66.501	1076	
218	436.0	-57.248	65.960	1068	
219	438.0	-57.248	65.600	1064	
220	440.0	-57.320	67.853	1100	
221	442.0	-57.536	70.015	1136	
222	444.0	-57.969	69.970	1133	
223	446.0	-58.185	68.168	1103	
224	448.0	-58.257	67.402	1093	
225	450.0	-58.401	69.249	1124	
226	452.0	-58.689	71.096	1154	peak
227	454.0	-59.193	70.421	1140	
228	456.0	-59.409	68.528	1110	
229	458.0	-59.481	67.717	1099	
230	460.0	-59.553	67.312	1090	
231	462.0	-59.625	68.258	1107	
232	464.0	-59.697	68.664	1114	
233	466.0	-59.769	68.754	1116	
234	468.0	-59.841	68.438	1110	
235	470.0	-59.913	68.664	1114	
236	472.0	-59.985	68.889	1118	
237	474.0	-60.129	69.610	1128	
238	476.0	-60.201	69.925	1135	
239	478.0	-60.417	70.105	1136	
240	480.0	-60.561	69.520	1126	
241	482.0	-60.633	69.384	1125	
242	484.0	-60.777	70.105	1137	
243	486.0	-60.993	70.466	1142	
244	488.0	-61.209	70.556	1143	
245	490.0	-61.497	70.331	1140	
246	492.0	-61.713	70.150	1138	
247	494.0	-61.857	69.024	1119	
248	496.0	-61.929	68.393	1110	
249	498.0	-61.929	67.943	1102	
250	500.0	-62.001	67.627	1097	
251	502.0	-62.001	67.402	1093	
252	504.0	-62.073	67.402	1094	
253	506.0	-62.073	67.537	1095	
254	508.0	-62.145	67.357	1091	

TRIAXIAL TEST/TRIAX7.DAT

Number of Readings 400 No. Columns 4
Date Task Started 01/01/83 Time Task Started 00-47-59

	Time Secs 1	displ7 mm 2	LOAD18 KN 3	LOAD NON 4
255	510.0	-62.145	67.132	1090
256	512.0	-62.145	66.996	1087
257	514.0	-62.145	66.906	1085
258	516.0	-62.145	66.771	1083
259	518.0	-62.145	66.681	1082
260	520.0	-62.145	66.591	1081
261	522.0	-62.217	66.501	1079
262	524.0	-62.217	66.411	1078
263	526.0	-62.217	66.366	1076
264	528.0	-62.217	66.276	1076
265	530.0	-62.217	66.231	1074
266	532.0	-62.217	66.140	1073
267	534.0	-62.217	66.095	1073
268	536.0	-62.217	66.005	1071
269	538.0	-62.217	65.960	1071
270	540.0	-62.289	65.915	1070
271	542.0	-62.289	65.870	1069
272	544.0	-62.289	65.825	1068
273	546.0	-62.289	65.780	1067
274	548.0	-62.289	65.690	1067
275	550.0	-62.289	65.645	1066
276	552.0	-62.289	65.600	1064
277	554.0	-62.289	65.555	1064
278	556.0	-62.289	65.510	1063
279	558.0	-62.289	65.465	1062
280	560.0	-62.289	65.420	1062
281	562.0	-62.289	65.375	1061
282	564.0	-62.289	65.329	1060
283	566.0	-62.289	65.284	1059
284	568.0	-62.289	65.239	1059
285	570.0	-62.361	65.239	1059
286	572.0	-62.361	65.194	1058
287	574.0	-62.361	65.149	1057
288	576.0	-62.361	65.104	1057
289	578.0	-62.361	65.059	1056
290	580.0	-62.361	65.059	1056
291	582.0	-62.361	65.014	1055
292	584.0	-62.361	64.969	1055
293	586.0	-62.361	64.924	1054
294	588.0	-62.361	64.924	1054
295	590.0	-62.361	64.879	1053
296	592.0	-62.361	64.879	1053
297	594.0	-62.361	64.834	1052
298	596.0	-62.361	64.789	1052
299	598.0	-62.361	64.744	1051
300	600.0	-62.361	64.744	1050
301	602.0	-62.361	64.699	1051
302	604.0	-62.361	64.699	1050
303	606.0	-62.361	64.654	1050
304	608.0	-62.361	64.654	1049
305	610.0	-62.361	64.609	1048

Number of Readings 400   No. Columns 4
Date Task Started 01/01/83   Time Task Started 00-47-59

	Time Secs 1	disp17 mm 2	LOAD18 KN 3	LOAD NON 4
306	612.0	-62.361	64.564	1049
307	614.0	-62.433	64.564	1047
308	616.0	-62.433	64.518	1047
309	618.0	-62.433	64.518	1048
310	620.0	-62.433	64.473	1047
311	622.0	-62.433	64.473	1046
312	624.0	-62.433	64.428	1046
313	626.0	-62.433	64.428	1045
314	628.0	-62.433	64.383	1045
315	630.0	-62.433	64.383	1045
316	632.0	-62.433	64.338	1043
317	634.0	-62.433	64.338	1044
318	636.0	-62.433	64.293	1044
319	638.0	-62.433	64.293	1043
320	640.0	-62.433	64.248	1043
321	642.0	-62.433	64.248	1043
322	644.0	-62.433	64.248	1042
323	646.0	-62.433	64.203	1041
324	648.0	-62.433	64.158	1042
325	650.0	-62.433	64.158	1042
326	652.0	-62.433	64.158	1042
327	654.0	-62.433	64.113	1040
328	656.0	-62.433	64.068	1040
329	658.0	-62.433	64.068	1040
330	660.0	-62.433	64.068	1039
331	662.0	-62.433	64.068	1039
332	664.0	-62.433	64.023	1039
333	666.0	-62.433	63.978	1038
334	668.0	-62.433	63.978	1039
335	670.0	-62.433	63.978	1037
336	672.0	-62.433	63.933	1039
337	674.0	-62.433	63.933	1038
338	676.0	-62.433	63.888	1037
339	678.0	-62.433	63.888	1037
340	680.0	-62.433	63.888	1037
341	682.0	-62.433	63.843	1037
342	684.0	-62.433	63.843	1036
343	686.0	-62.505	63.843	1036
344	688.0	-62.505	63.798	1036
345	690.0	-62.505	63.798	1036
346	692.0	-62.505	63.798	1035
347	694.0	-62.433	63.753	1035
348	696.0	-62.433	63.753	1036
349	698.0	-62.505	63.753	1034
350	700.0	-62.505	63.707	1035
351	702.0	-62.505	63.707	1035
352	704.0	-62.505	63.707	1035
353	706.0	-62.505	63.662	1034
354	708.0	-62.505	63.662	1033
355	710.0	-62.505	63.662	1032
356	712.0	-62.505	63.617	1033

Number of Readings 400   No. Columns 4
Date Task Started 01/01/83   Time Task Started 00-47-59

	Time Secs 1	disp17 mm 2	LOAD18 KN 3	LOAD NON 4
357	714.0	-62.505	63.617	1034
358	716.0	-62.505	63.617	1032
359	718.0	-62.505	63.572	1032
360	720.0	-62.505	63.572	1032
361	722.0	-62.505	63.572	1032
362	724.0	-62.505	63.527	1032
363	726.0	-62.505	63.527	1032
364	728.0	-62.505	63.527	1031
365	730.0	-62.505	63.482	1031
366	732.0	-62.505	63.482	1031
367	734.0	-62.505	63.482	1030
368	736.0	-62.505	63.482	1030
369	738.0	-62.505	63.437	1029
370	740.0	-62.505	63.437	1029
371	742.0	-62.505	63.437	1029
372	744.0	-62.505	63.437	1029
373	746.0	-62.505	63.392	1029
374	748.0	-62.505	63.392	1029
375	750.0	-62.505	63.392	1028
376	752.0	-62.505	63.347	1029
377	754.0	-62.505	63.347	1029
378	756.0	-62.505	63.347	1029
379	758.0	-62.505	63.302	1028
380	760.0	-62.505	63.302	1028
381	762.0	-62.505	63.302	1028
382	764.0	-62.577	63.302	1027
383	766.0	-62.505	63.257	1027
384	768.0	-62.505	63.257	1027
385	770.0	-62.505	63.257	1027
386	772.0	-62.505	63.212	1026
387	774.0	-62.505	63.212	1027
388	776.0	-62.577	63.212	1026
389	778.0	-62.577	63.212	1025
390	780.0	-62.577	63.167	1026
391	782.0	-62.505	63.167	1026
392	784.0	-62.505	63.167	1026
393	786.0	-62.577	63.167	1025
394	788.0	-62.505	63.122	1025
395	790.0	-62.577	63.122	1025
396	792.0	-62.577	63.122	1025
397	794.0	-62.505	63.122	1025
398	796.0	-62.505	63.077	1025
399	798.0	-62.577	63.077	1024
400	800.0	-62.505	63.077	1025

CALCULATION SHEET FOR TEST .... Triax 8

Peak axial load difference [kN] = 82.68

Axial compression [mm] = 34.5

} combination giving peak stress

Cross - sectional area [m^2] = 0.566

Stress difference, $\sigma_1 - \sigma_3$ [kN/m^2] = 1461

Cell pressure, σ_3 [kN/m^2] = 400

Angle of friction, ϕ = **40.27°**

Axial load difference at 10% axial strain [kN] = 76.73

Stress difference, $\sigma_1 - \sigma_3$ [kN/m^2] = 1363

Cell pressure, σ_3 [kN/m^2] = 400

Angle of friction, ϕ = **39.0°**

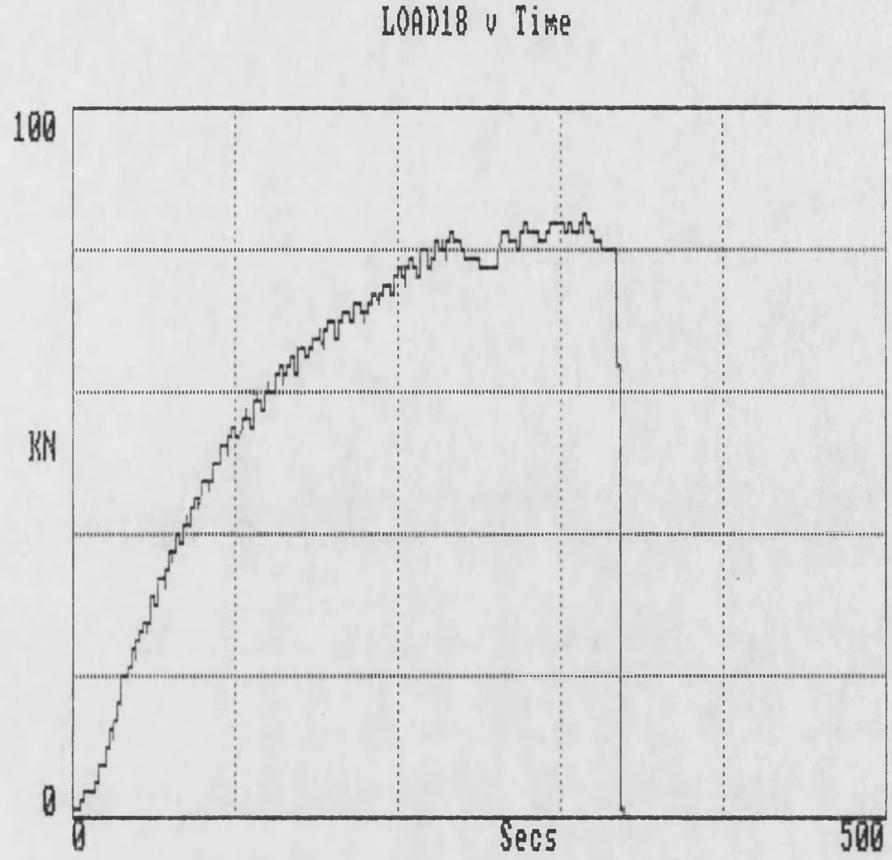
$$\text{Cross - sectional area} = \frac{\text{Sample volume}}{\text{Orig. height - axial comp.}}$$

$$\text{Angle of friction determined from; } \sin\phi = \frac{\sigma_1 - \sigma_3}{\sigma_1 + \sigma_3}$$

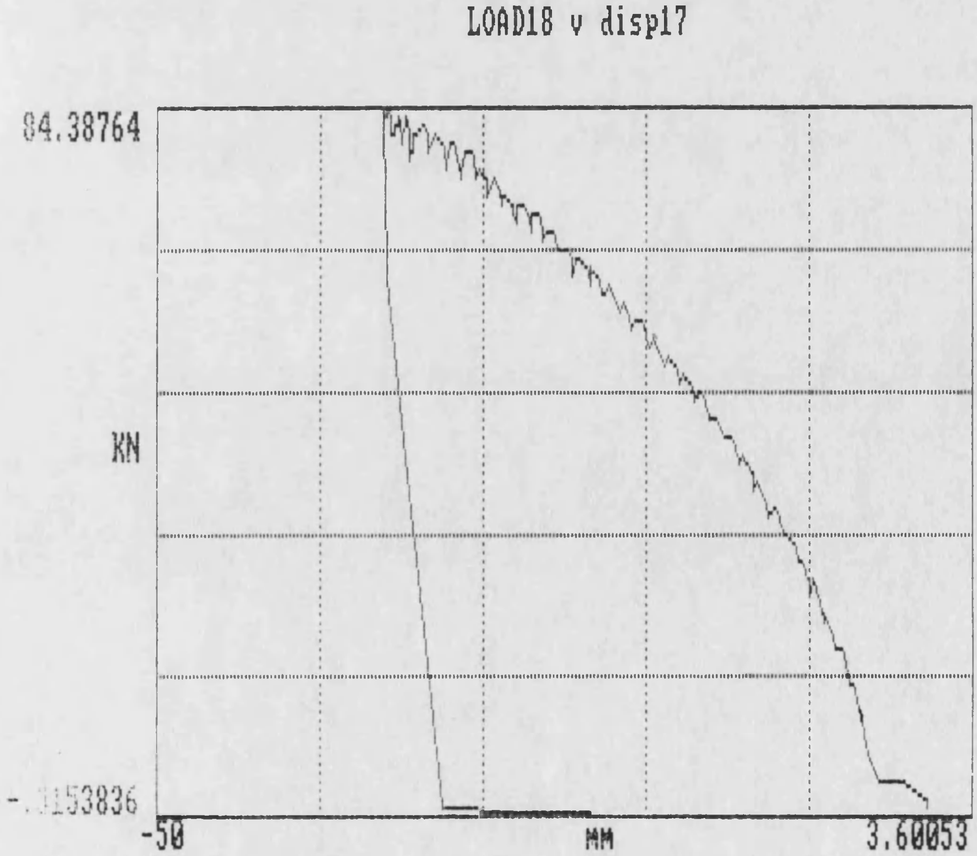
Sample volume = 0.017 m^3,

Original sample height = 335mm,

Cross - sectional area at 10% strain = 0.0563 m^2



LOAD18 v Time
100
KN
0
0
Secs
500



LOAD18 v disp17
84.38764
KN
-.0153836
-50
MM
3.60053

Number of Readings 267 No. Columns 4
Date Task Started 01/01/83 Time Task Started 01-03-29

	Time Secs 1	displ7 mm 2	LOAD18 KN 3	LOAD NON 4
0	0.0	0.720	1.712	28
1	2.0	0.720	1.712	28
2	4.0	0.720	1.712	28
3	6.0	0.720	1.757	28
4	8.0	0.720	1.712	27
5	10.0	0.720	1.712	28
6	12.0	0.720	1.712	27
7	14.0	0.792	1.712	27
8	16.0	0.792	1.712	27
9	18.0	-0.792	3.694	62
10	20.0	-1.152	3.649	60
11	22.0	-1.728	4.235	71
12	24.0	-2.376	4.100	67
13	26.0	-2.808	4.956	84
14	28.0	-3.168	7.479	126
15	30.0	-3.168	7.119	118
16	32.0	-3.384	9.191	156
17	34.0	-3.673	12.030	203
18	36.0	-3.817	11.759	195
19	38.0	-4.249	15.949	268
20	40.0	-4.537	15.679	260
21	42.0	-5.041	19.779	329
22	44.0	-5.329	19.644	324
23	46.0	-5.617	21.807	362
24	48.0	-6.049	24.059	398
25	50.0	-6.265	23.023	378
26	52.0	-6.409	25.276	418
27	54.0	-6.913	27.754	459
28	56.0	-7.057	26.627	438
29	58.0	-7.129	27.393	455
30	60.0	-7.633	30.682	509
31	62.0	-7.921	30.052	496
32	64.0	-8.137	32.485	539
33	66.0	-8.641	34.016	563
34	68.0	-8.857	33.070	546
35	70.0	-9.217	36.359	604
36	72.0	-9.793	36.134	597
37	74.0	-9.937	37.711	627
38	76.0	-10.514	40.369	670
39	78.0	-10.802	38.657	639
40	80.0	-10.874	40.820	680
41	82.0	-11.522	42.892	710
42	84.0	-11.738	42.487	706
43	86.0	-12.170	45.145	750
44	88.0	-12.602	45.010	745
45	90.0	-12.746	45.686	760
46	92.0	-13.178	47.578	789
47	94.0	-13.610	47.533	786
48	96.0	-13.754	47.443	787
49	98.0	-14.258	50.416	835
50	100.0	-14.690	49.425	817

TRIAXIAL TEST/TRIAX8.DAT

Number of Readings 267 No. Columns 4
Date Task Started 01/01/83 Time Task Started 01-03-29

	Time Secs 1	displ7 mm 2	LOAD18 KN 3	LOAD NON 4
51	102.0	-14.906	51.903	862
52	104.0	-15.410	52.714	873
53	106.0	-15.698	51.633	853
54	108.0	-15.842	53.795	894
55	110.0	-16.274	54.606	904
56	112.0	-16.634	54.201	896
57	114.0	-16.706	54.201	898
58	116.0	-16.994	56.183	931
59	118.0	-17.427	56.994	943
60	120.0	-17.643	55.913	924
61	122.0	-17.787	57.084	948
62	124.0	-18.147	59.022	978
63	126.0	-18.579	58.751	970
64	128.0	-18.723	57.940	959
65	130.0	-18.939	60.509	1003
66	132.0	-19.371	61.365	1017
67	134.0	-19.659	59.833	990
68	136.0	-19.803	60.644	1006
69	138.0	-20.163	63.257	1048
70	140.0	-20.595	62.311	1029
71	142.0	-20.667	62.086	1029
72	144.0	-20.955	64.113	1063
73	146.0	-21.387	65.014	1076
74	148.0	-21.603	63.392	1049
75	150.0	-21.747	65.104	1082
76	152.0	-22.179	66.366	1098
77	154.0	-22.539	65.870	1089
78	156.0	-22.683	64.564	1067
79	158.0	-22.755	66.186	1097
80	160.0	-22.971	67.132	1112
81	162.0	-23.259	67.807	1121
82	164.0	-23.475	67.267	1111
83	166.0	-23.619	67.672	1120
84	168.0	-23.836	69.204	1144
85	170.0	-24.196	69.520	1148
86	172.0	-24.412	69.114	1140
87	174.0	-24.556	67.988	1122
88	176.0	-24.628	69.429	1148
89	178.0	-24.916	71.322	1179
90	180.0	-25.276	71.322	1175
91	182.0	-25.492	69.745	1149
92	184.0	-25.636	71.367	1179
93	186.0	-25.924	72.763	1200
94	188.0	-26.284	72.403	1192
95	190.0	-26.428	70.916	1167
96	192.0	-26.500	71.592	1181
97	194.0	-26.716	72.944	1202
98	196.0	-27.004	73.845	1215
99	198.0	-27.220	73.665	1210
100	200.0	-27.364	72.403	1190
101	202.0	-27.580	75.061	1235

TRIAXIAL TEST/TRIAX8.DAT

Number of Readings 267 No. Columns 4
Date Task Started 01/01/83 Time Task Started 01-03-29

	Time Secs 1	displ7 mm 2	LOAD18 KN 3	LOAD NON 4	
102	204.0	-27.868	75.422	1238	
103	206.0	-28.084	74.791	1226	
104	208.0	-28.228	73.710	1206	
105	210.0	-28.372	76.143	1249	
106	212.0	-28.732	77.314	1265	
107	214.0	-29.020	76.188	1242	
108	216.0	-29.092	76.323	1248	
109	218.0	-29.308	78.576	1286	
110	220.0	-29.740	78.936	1290	
111	222.0	-29.956	77.179	1260	
112	224.0	-30.100	76.368	1247	
113	226.0	-30.388	80.333	1317	
114	228.0	-30.821	79.792	1305	
115	230.0	-31.037	78.035	1275	
116	232.0	-31.109	77.179	1263	
117	234.0	-31.253	80.107	1313	
118	236.0	-31.613	80.828	1324	
119	238.0	-31.973	80.648	1320	
120	240.0	-32.117	79.161	1297	
121	242.0	-32.261	81.099	1331	
122	244.0	-32.549	82.315	1350	
123	246.0	-32.837	81.639	1339	
124	248.0	-33.125	80.873	1325	
125	250.0	-33.197	79.927	1309	
126	252.0	-33.269	79.387	1300	
127	254.0	-33.269	78.981	1294	
128	256.0	-33.341	78.666	1289	
129	258.0	-33.341	78.440	1284	10%
130	260.0	-33.341	78.215	1281	
131	262.0	-33.341	78.080	1277	
132	264.0	-33.413	77.900	1275	
133	266.0	-33.413	77.810	1272	
134	268.0	-33.413	77.674	1271	
135	270.0	-33.413	77.539	1269	
136	272.0	-33.413	78.621	1288	
137	274.0	-33.485	80.783	1323	
138	276.0	-33.557	82.811	1358	
139	278.0	-33.701	82.540	1352	
140	280.0	-33.845	81.549	1335	
141	282.0	-33.917	80.963	1325	
142	284.0	-33.917	80.558	1317	
143	286.0	-33.989	80.288	1312	
144	288.0	-34.061	82.901	1358	
145	290.0	-34.205	83.261	1364	
146	292.0	-34.277	82.631	1352	
147	294.0	-34.421	82.585	1350	
148	296.0	-34.421	81.910	1338	
149	298.0	-34.493	81.459	1331	
150	300.0	-34.493	81.099	1324	
151	302.0	-34.565	81.594	1333	
152	304.0	-34.565	82.901	1355	

Number of Readings 267 No. Columns 4
Date Task Started 01/01/83 Time Task Started 01-03-29

	Time Secs 1	displ7 mm 2	LOAD18 KN 3	LOAD NON 4	
153	306.0	-34.637	83.577	1367	
154	308.0	-34.709	83.667	1370	
155	310.0	-34.853	84.117	1379	
156	312.0	-34.853	83.351	1366	
157	314.0	-34.925	82.901	1359	
158	316.0	-34.997	83.712	1373	
159	318.0	-35.069	82.901	1359	
160	320.0	-35.069	82.405	1350	
161	322.0	-35.141	82.045	1345	
162	324.0	-35.141	83.261	1366	
163	326.0	-35.213	84.388	1389	peak
164	328.0	-35.213	84.027	1385	
165	330.0	-35.213	82.856	1366	
166	332.0	-35.141	82.000	1351	
167	334.0	-35.141	81.189	1341	
168	336.0	-35.141	80.738	1335	
169	338.0	-35.069	80.423	1331	
170	340.0	-35.141	80.198	1328	
171	342.0	-35.069	80.017	1326	
172	344.0	-35.141	79.837	1324	
173	346.0	-34.853	63.347	979	
174	348.0	-31.325	0.856	10	
175	350.0	-11.810	0.180	6	
176	352.0	3.529	-0.315	-1	
177	354.0	3.529	-0.270	0	
178	356.0	3.529	-0.270	-1	
179	358.0	3.529	-0.270	-1	
180	360.0	3.529	-0.270	-1	
181	362.0	3.529	-0.225	1	
182	364.0	3.529	-0.225	-1	
183	366.0	3.529	-0.225	1	
184	368.0	3.529	-0.225	1	
185	370.0	3.529	-0.225	0	
186	372.0	3.601	-0.225	-0	
187	374.0	3.529	-0.225	-0	
188	376.0	3.529	-0.180	0	
189	378.0	3.529	-0.180	0	
190	380.0	3.529	-0.180	1	
191	382.0	3.529	-0.180	-1	
192	384.0	3.529	-0.180	-0	
193	386.0	3.529	-0.180	0	
194	388.0	3.529	-0.180	0	
195	390.0	3.529	-0.180	-0	
196	392.0	3.529	-0.180	0	
197	394.0	3.529	-0.135	-1	
198	396.0	3.529	-0.180	-2	
199	398.0	3.529	-0.180	-3	
200	400.0	3.601	-0.135	-5	
201	402.0	3.529	-0.180	-6	
202	404.0	3.529	-0.180	-5	
203	406.0	3.529	-0.135	-4	

Number of Readings 267 No. Columns 4
Date Task Started 01/01/83 Time Task Started 01-03-29

	Time Secs 1	disp17 mm 2	LOAD18 KN 3	LOAD NON 4
204	408.0	3.529	-0.135	-5
205	410.0	3.529	-0.180	-5
206	412.0	3.529	-0.135	-5
207	414.0	3.529	-0.135	-5
208	416.0	3.529	-0.135	-4
209	418.0	3.529	-0.135	-5
210	420.0	3.529	-0.135	-4
211	422.0	3.529	-0.135	-4
212	424.0	3.529	-0.135	-5
213	426.0	3.529	-0.135	-5
214	428.0	3.529	-0.135	-5
215	430.0	3.529	-0.135	-5
216	432.0	3.601	-0.135	-5
217	434.0	-5.761	-0.135	-5
218	436.0	-13.034	-0.135	-4
219	438.0	-24.700	-0.135	-5
220	440.0	-43.926	-0.135	-5
221	442.0	-589.911	-0.135	-4
222	444.0	-589.911	-0.135	-5
223	446.0	-589.911	-0.090	-5
224	448.0	-589.911	-0.090	-6
225	450.0	-589.911	-0.135	-5
226	452.0	-589.911	-0.135	-5
227	454.0	-589.911	-0.135	-4
228	456.0	-589.911	-0.135	-4
229	458.0	-589.911	-0.135	-4
230	460.0	-589.911	-0.135	-4
231	462.0	-589.911	-0.135	-5
232	464.0	-589.911	-0.135	-5
233	466.0	-589.911	-0.090	-5
234	468.0	-31.325	-0.135	-4
235	470.0	-589.911	-0.135	-5
236	472.0	-589.911	-0.090	-5
237	474.0	-589.911	-0.135	-5
238	476.0	-56.024	-0.090	-4
239	478.0	-37.518	-0.135	-5
240	480.0	-37.590	-0.135	-4
241	482.0	-37.590	-0.090	-5
242	484.0	-48.031	-0.090	-4
243	486.0	-589.911	-0.090	-5
244	488.0	-58.041	-0.090	-5
245	490.0	-63.369	-0.090	-5
246	492.0	-67.258	-0.135	-5
247	494.0	-67.258	-0.090	-4
248	496.0	-57.032	-0.090	-4
249	498.0	-20.523	-0.135	-5
250	500.0	-41.046	-0.090	-4
251	502.0	-37.374	-0.090	-5
252	504.0	-42.486	-0.090	-5
253	506.0	-37.806	-0.090	-5
254	508.0	-13.034	-0.090	-5

TRIAXIAL TEST/TRIAX8.DAT

Number of Readings 267 No. Columns 4
Date Task Started 01/01/83 Time Task Started 01-03-29

	Time Secs 1	disp17 mm 2	LOAD18 KN 3	LOAD NON 4
255	510.0	-65.890	-0.090	-4
256	512.0	-31.613	-0.090	-5
257	514.0	-45.943	-0.090	-5
258	516.0	-56.240	-0.090	-6
259	518.0	-56.240	-0.090	-5
260	520.0	-56.096	-0.090	-6
261	522.0	-55.880	-0.090	-5
262	524.0	-55.808	-0.090	-5
263	526.0	-55.808	-0.090	-5
264	528.0	-55.808	-0.090	-5
265	530.0	-55.736	-0.090	-5
266	532.0	-55.664	-0.090	-6
267	534.0	-55.592	-0.090	-6

CALCULATION SHEET FOR TEST .... Triax 9.

Cell pressure increase during test. Peak void.

Peak axial load difference [kN] = ⎫ combination

Axial compression [mm] = ⎬ giving peak stress ⎭

Cross - sectional area [m^2] =

Stress difference, $\sigma_1 - \sigma_3$ [kN/m^2] =

Cell pressure, σ_3 [kN/m^2] =

Angle of friction, ϕ =

Axial load difference at 10% axial strain [kN] = 34.69

Stress difference, $\sigma_1 - \sigma_3$ [kN/m^2] = 616

Cell pressure, σ_3 [kN/m^2] = 100

Angle of friction, ϕ = **49.0°**

$$\text{Cross - sectional area} = \frac{\text{Sample volume}}{\text{Orig. height - axial comp.}}$$

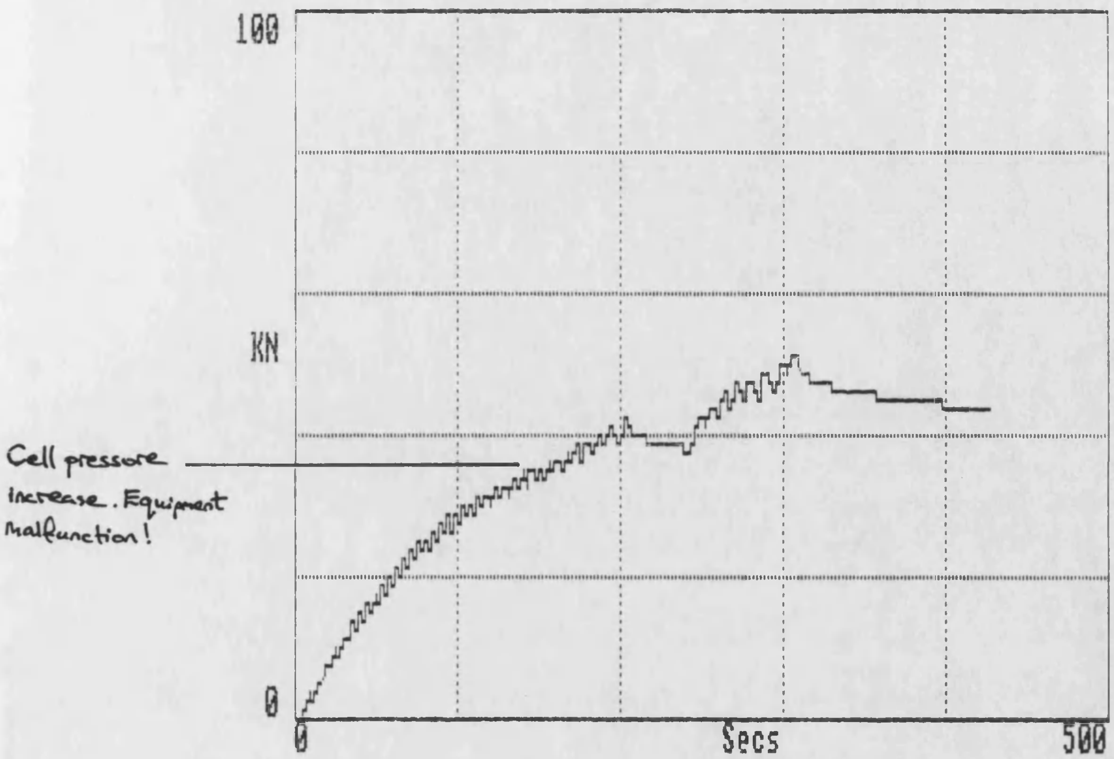
$$\text{Angle of friction determined from; } \sin\phi = \frac{\sigma_1 - \sigma_3}{\sigma_1 + \sigma_3}$$

Sample volume = 0.017 m^3,

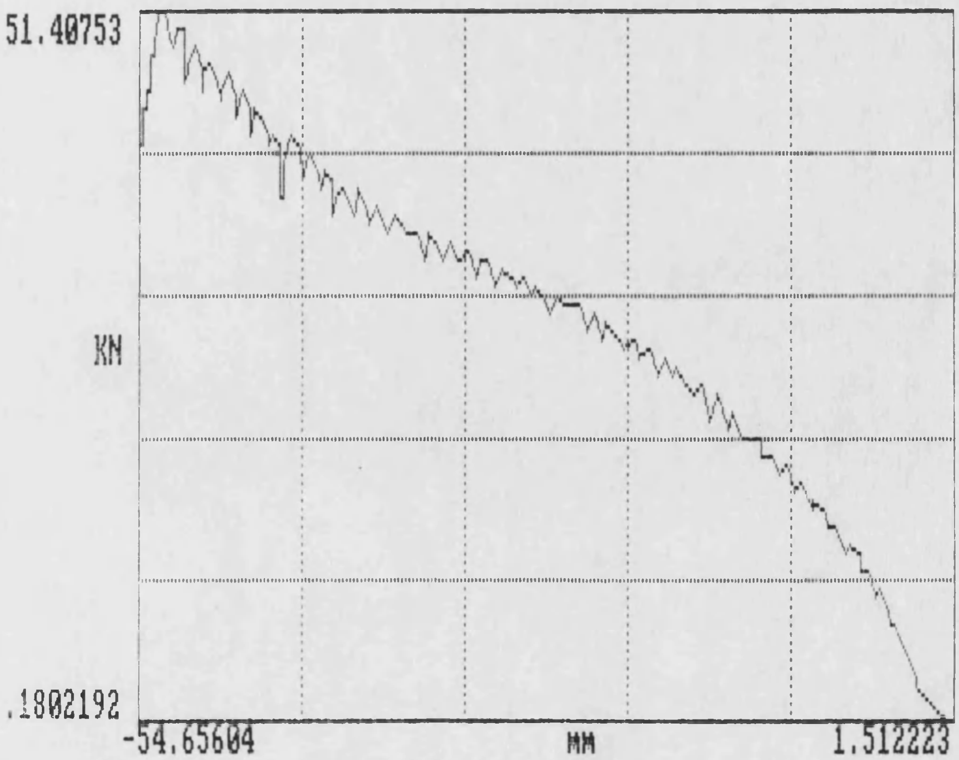
Original sample height = 335mm,

Cross - sectional area at 10% strain = 0.0563 m^2

LOAD18 v Time



LOAD18 v disp17



Number of Readings 324 No. Columns 4
Date Task Started 01/01/83 Time Task Started 00-13-43

	Time Secs 1	disp17 mm 2	LOAD18 KN 3	LOAD NON 4
0	0.0	1.440	0.180	2
1	2.0	1.368	0.180	3
2	4.0	1.440	0.180	3
3	6.0	1.440	0.225	2
4	8.0	1.440	0.180	3
5	10.0	1.440	0.180	2
6	12.0	1.440	0.180	2
7	14.0	1.440	0.180	2
8	16.0	1.440	0.180	3
9	18.0	1.440	0.225	3
10	20.0	1.440	0.180	3
11	22.0	1.440	0.180	3
12	24.0	1.440	0.180	3
13	26.0	1.440	0.180	4
14	28.0	1.440	0.180	4
15	30.0	1.440	0.225	3
16	32.0	1.440	0.180	2
17	34.0	1.440	0.180	3
18	36.0	1.512	0.180	2
19	38.0	1.440	0.225	3
20	40.0	1.440	0.180	2
21	42.0	1.440	0.180	2
22	44.0	1.440	0.180	3
23	46.0	1.440	0.180	2
24	48.0	1.440	0.225	3
25	50.0	1.440	0.180	3
26	52.0	1.512	0.180	3
27	54.0	1.512	0.180	1
28	56.0	1.512	0.180	3
29	58.0	1.512	0.225	2
30	60.0	1.512	0.180	3
31	62.0	1.512	0.225	4
32	64.0	0.576	0.721	12
33	66.0	-0.936	2.793	46
34	68.0	-1.080	3.154	52
35	70.0	-1.152	3.649	61
36	72.0	-1.440	4.911	81
37	74.0	-1.800	5.452	90
38	76.0	-1.944	6.037	101
39	78.0	-2.520	7.434	124
40	80.0	-2.808	7.389	121
41	82.0	-3.096	8.786	146
42	84.0	-3.673	9.597	159
43	86.0	-3.817	9.146	152
44	88.0	-4.249	10.993	183
45	90.0	-4.825	11.129	183
46	92.0	-4.969	12.075	203
47	94.0	-5.761	13.156	220
48	96.0	-5.977	12.525	208
49	98.0	-6.553	14.508	243
50	100.0	-7.057	14.192	234

Number of Readings 324 No. Columns 4
Date Task Started 01/01/83 Time Task Started 00-13-43

	Time Secs 1	disp17 mm 2	LOAD18 KN 3	LOAD NON 4
51	102.0	-7.345	15.724	263
52	104.0	-8.137	16.040	266
53	106.0	-8.209	15.229	253
54	108.0	-8.929	17.616	293
55	110.0	-9.361	16.760	277
56	112.0	-9.865	18.788	313
57	114.0	-10.514	18.112	299
58	116.0	-10.874	19.644	327
59	118.0	-11.666	19.554	322
60	120.0	-11.882	20.635	344
61	122.0	-12.818	20.905	346
62	124.0	-12.962	20.905	347
63	126.0	-13.898	22.753	376
64	128.0	-14.114	21.266	351
65	130.0	-14.834	23.609	391
66	132.0	-15.266	22.257	366
67	134.0	-15.770	24.420	405
68	136.0	-16.418	23.609	388
69	138.0	-16.778	24.645	408
70	140.0	-17.571	25.501	419
71	142.0	-17.787	24.870	411
72	144.0	-18.507	26.357	434
73	146.0	-19.011	25.050	413
74	148.0	-19.515	27.078	445
75	150.0	-20.091	26.267	430
76	152.0	-20.451	27.754	457
77	154.0	-21.315	27.393	448
78	156.0	-21.531	27.889	459
79	158.0	-22.467	29.196	479
80	160.0	-22.683	27.438	451
81	162.0	-23.331	29.691	488
82	164.0	-23.836	28.430	464
83	166.0	-24.196	30.187	496
84	168.0	-24.988	30.007	490
85	170.0	-25.204	30.232	496
86	172.0	-25.924	31.133	510
87	174.0	-26.284	29.691	484
88	176.0	-26.716	31.178	510
89	178.0	-27.436	31.628	515
90	180.0	-27.652	31.088	510
91	182.0	-28.228	32.394	530
92	184.0	-28.732	31.313	510
93	186.0	-28.948	32.079	525
94	188.0	-29.668	33.025	539
95	190.0	-30.028	31.538	513
96	192.0	-30.532	33.431	546
97	194.0	-31.181	33.296	541
98	196.0	-31.325	32.034	527
99	198.0	-31.973	34.242	558
100	200.0	-32.477	33.476	[illegible]
101	202.0	-32.693	[illegible]	[illegible]

Number of Readings 324 No. Columns 4
Date Task Started 01/01/83 Time Task Started 00-13-43

	Time Secs 1	disp17 mm 2	LOAD18 KN 3	LOAD NON 4
102	204.0	-33.269	34.872	567
103	206.0	-33.773	33.476	543
104	208.0	-34.133	34.917	569
105	210.0	-34.853	35.503	579
106	212.0	-35.069	33.701	549
107	214.0	-35.573	35.548	579
108	216.0	-36.149	35.458	574
109	218.0	-36.437	35.774	583
110	220.0	-37.085	36.584	594
111	222.0	-37.518	35.413	574
112	224.0	-37.734	35.954	586
113	226.0	-38.310	37.486	609
114	228.0	-38.742	36.044	583
115	230.0	-38.958	37.260	607
116	232.0	-39.606	38.477	625
117	234.0	-39.966	36.449	591
118	236.0	-40.038	37.215	607
119	238.0	-40.614	38.702	628
120	240.0	-41.118	38.206	617
121	242.0	-41.262	36.945	598
122	244.0	-41.478	39.063	633
123	246.0	-41.910	40.099	650
124	248.0	-42.270	38.657	625
125	250.0	-42.414	39.828	646
126	252.0	-42.846	41.135	666
127	254.0	-43.278	40.775	659
128	256.0	-43.422	39.513	637
129	258.0	-43.494	39.108	633
130	260.0	-43.710	41.676	675
131	262.0	-44.143	42.171	681
132	264.0	-44.503	41.495	670
133	266.0	-44.575	40.549	656
134	268.0	-44.647	40.099	649
135	270.0	-44.647	39.783	643
136	272.0	-44.719	39.558	640
137	274.0	-44.719	39.378	637
138	276.0	-44.719	39.198	635
139	278.0	-44.719	39.063	632
140	280.0	-44.791	38.927	630
141	282.0	-44.791	38.792	627
142	284.0	-44.791	38.702	626
143	286.0	-44.791	38.567	625
144	288.0	-44.791	38.477	623
145	290.0	-44.791	38.387	622
146	292.0	-44.791	38.297	621
147	294.0	-44.791	38.252	620
148	296.0	-44.863	38.206	619
149	298.0	-44.791	38.116	617
150	300.0	-44.863	38.026	616
151	302.0	-44.863	37.981	615
152	304.0	-44.935	40.054	650

10%

Number of Readings 324 No. Columns 4
Date Task Started 01/01/83 Time Task Started 00-13-43

	Time Secs 1	disp17 mm 2	LOAD18 KN 3	LOAD NON 4
153	306.0	-45.079	41.991	680
154	308.0	-45.439	42.487	687
155	310.0	-45.727	41.541	670
156	312.0	-45.799	42.216	684
157	314.0	-46.231	43.793	708
158	316.0	-46.663	44.064	711
159	318.0	-46.879	42.622	687
160	320.0	-46.951	44.109	714
161	322.0	-47.455	45.686	738
162	324.0	-47.887	44.920	723
163	326.0	-48.031	43.793	706
164	328.0	-48.103	44.875	727
165	330.0	-48.607	47.037	760
166	332.0	-48.967	45.821	738
167	334.0	-49.111	44.920	725
168	336.0	-49.471	47.217	763
169	338.0	-49.903	47.758	771
170	340.0	-50.191	46.677	752
171	342.0	-50.335	45.821	738
172	344.0	-50.407	46.992	761
173	346.0	-50.839	48.930	789
174	348.0	-51.200	48.524	780
175	350.0	-51.344	47.308	763
176	352.0	-51.416	46.677	753
177	354.0	-51.488	46.316	747
178	356.0	-51.632	49.831	807
179	358.0	-52.136	50.056	807
180	360.0	-52.424	48.659	784
181	362.0	-52.568	49.380	797
182	364.0	-52.928	51.408	830
183	366.0	-53.432	51.092	823
184	368.0	-53.648	49.515	798
185	370.0	-53.720	48.884	787
186	372.0	-53.720	48.434	781
187	374.0	-53.792	48.073	776
188	376.0	-53.792	47.848	772
189	378.0	-53.864	47.623	768
190	380.0	-53.864	47.443	765
191	382.0	-53.864	47.262	762
192	384.0	-53.864	47.172	760
193	386.0	-53.936	47.037	758
194	388.0	-53.936	46.902	756
195	390.0	-53.936	46.767	754
196	392.0	-53.936	46.677	753
197	394.0	-53.936	46.587	751
198	396.0	-53.936	46.452	750
199	398.0	-54.008	46.361	748
200	400.0	-54.008	46.271	746
201	402.0	-54.008	46.181	745
202	404.0	-54.008	46.091	743
203	406.0	-54.008	45.956	741

Number of Readings 324 No. Columns 4
Date Task Started 01/01/83 Time Task Started 00-13-43

	Time Secs 1	displ7 mm 2	LOAD18 KN 3	LOAD NON 4
204	408.0	-54.080	45.911	741
205	410.0	-54.080	45.776	739
206	412.0	-54.080	45.731	737
207	414.0	-54.080	45.641	737
208	416.0	-54.080	45.550	736
209	418.0	-54.080	45.505	734
210	420.0	-54.080	45.415	733
211	422.0	-54.080	45.325	731
212	424.0	-54.080	45.280	730
213	426.0	-54.152	45.190	728
214	428.0	-54.152	45.145	728
215	430.0	-54.152	45.100	729
216	432.0	-54.152	45.010	726
217	434.0	-54.152	44.965	725
218	436.0	-54.152	44.875	724
219	438.0	-54.152	44.830	724
220	440.0	-54.152	44.784	723
221	442.0	-54.152	44.739	722
222	444.0	-54.152	44.694	721
223	446.0	-54.152	44.604	721
224	448.0	-54.224	44.559	719
225	450.0	-54.224	44.514	719
226	452.0	-54.224	44.469	718
227	454.0	-54.224	44.424	717
228	456.0	-54.224	44.379	716
229	458.0	-54.224	44.289	716
230	460.0	-54.224	44.244	714
231	462.0	-54.224	44.199	714
232	464.0	-54.224	44.154	713
233	466.0	-54.224	44.064	712
234	468.0	-54.296	44.064	711
235	470.0	-54.296	43.973	709
236	472.0	-54.296	43.928	709
237	474.0	-54.296	43.883	708
238	476.0	-54.296	43.838	708
239	478.0	-54.296	43.793	706
240	480.0	-54.296	43.748	706
241	482.0	-54.296	43.703	705
242	484.0	-54.296	43.613	705
243	486.0	-54.296	43.568	703
244	488.0	-54.296	43.523	702
245	490.0	-54.296	43.523	702
246	492.0	-54.296	43.433	702
247	494.0	-54.368	43.388	701
248	496.0	-54.368	43.343	700
249	498.0	-54.368	43.298	700
250	500.0	-54.368	43.253	699
251	502.0	-54.368	43.208	698
252	504.0	-54.368	43.162	697
253	506.0	-54.368	43.117	696
254	508.0	-54.368	43.072	696

Number of Readings 324 No. Columns 4
Date Task Started 01/01/83 Time Task Started 00-13-43

	Time Secs 1	displ7 mm 2	LOAD18 KN 3	LOAD NON 4
255	510.0	-54.368	43.027	695
256	512.0	-54.368	42.982	693
257	514.0	-54.368	42.937	694
258	516.0	-54.368	42.892	692
259	518.0	-54.368	42.847	692
260	520.0	-54.440	42.802	691
261	522.0	-54.440	42.757	691
262	524.0	-54.440	42.712	690
263	526.0	-54.440	42.667	690
264	528.0	-54.440	42.577	688
265	530.0	-54.440	42.577	687
266	532.0	-54.440	42.532	687
267	534.0	-54.440	42.487	685
268	536.0	-54.440	42.442	686
269	538.0	-54.440	42.397	685
270	540.0	-54.440	42.352	684
271	542.0	-54.440	42.306	683
272	544.0	-54.440	42.261	683
273	546.0	-54.440	42.216	682
274	548.0	-54.512	42.171	682
275	550.0	-54.440	42.171	681
276	552.0	-54.512	42.081	681
277	554.0	-54.440	42.081	680
278	556.0	-54.512	42.036	678
279	558.0	-54.512	41.991	678
280	560.0	-54.512	41.946	678
281	562.0	-54.512	41.946	676
282	564.0	-54.512	41.901	677
283	566.0	-54.512	41.856	676
284	568.0	-54.512	41.811	675
285	570.0	-54.512	41.766	675
286	572.0	-54.512	41.766	674
287	574.0	-54.512	41.721	673
288	576.0	-54.512	41.676	673
289	578.0	-54.512	41.631	673
290	580.0	-54.584	41.586	673
291	582.0	-54.584	41.541	672
292	584.0	-54.584	41.541	671
293	586.0	-54.584	41.495	671
294	588.0	-54.584	41.450	669
295	590.0	-54.584	41.405	669
296	592.0	-54.584	41.360	668
297	594.0	-54.584	41.360	668
298	596.0	-54.584	41.315	668
299	598.0	-54.584	41.270	667
300	600.0	-54.584	41.270	666
301	602.0	-54.584	41.225	666
302	604.0	-54.584	41.180	666
303	606.0	-54.584	41.135	665
304	608.0	-54.584	41.135	664
305	610.0	-54.584	41.090	663

Number of Readings 324 No. Columns 4
Date Task Started 01/01/83 Time Task Started 00-13-43

	Time Secs 1	disp17 mm 2	LOAD18 KN 3	LOAD NON 4
306	612.0	-54.584	41.045	664
307	614.0	-54.584	41.000	663
308	616.0	-54.584	41.000	662
309	618.0	-54.584	40.955	662
310	620.0	-54.656	40.910	661
311	622.0	-54.656	40.865	660
312	624.0	-54.656	40.820	660
313	626.0	-54.656	40.820	659
314	628.0	-54.656	40.775	659
315	630.0	-54.656	40.775	659
316	632.0	-54.656	40.730	658
317	634.0	-54.656	40.730	658
318	636.0	-54.656	40.684	657
319	638.0	-54.656	40.639	657
320	640.0	-54.656	40.639	656
321	642.0	-54.656	40.594	656
322	644.0	-54.656	40.549	655
323	646.0	-54.656	40.504	654
324	648.0	-54.656	40.459	654

CALCULATION SHEET FOR TEST .... Triax 10

With membrane protection.

Peak axial load difference [kN] = 30.2

Axial compression [mm] = 48.25

} combination giving peak stress

Cross - sectional area [m^2] = 0.0593

Stress difference, $\sigma_1 - \sigma_3$ [kN/m^2] = 509

Cell pressure, σ_3 [kN/m^2] = 100

Angle of friction, ϕ = **45.88°**

Axial load difference at 10% axial strain [kN] = 25.68

Stress difference, $\sigma_1 - \sigma_3$ [kN/m^2] = 456

Cell pressure, σ_3 [kN/m^2] = 100

Angle of friction, ϕ = **44.1°**

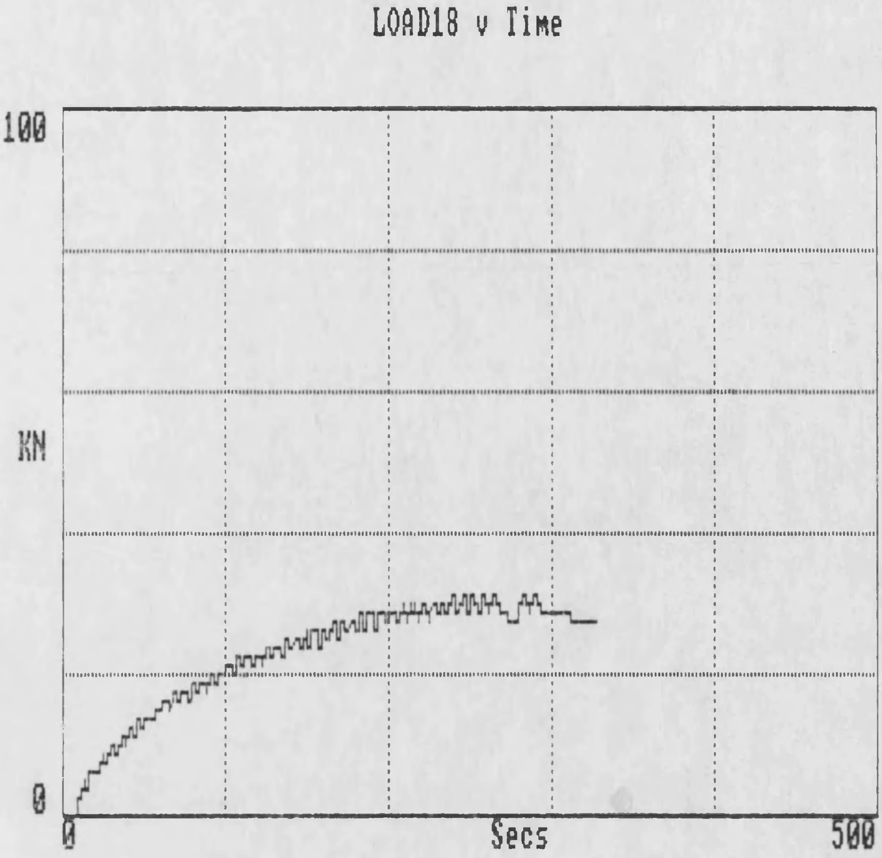
$$\text{Cross - sectional area} = \frac{\text{Sample volume}}{\text{Orig. height - axial comp.}}$$

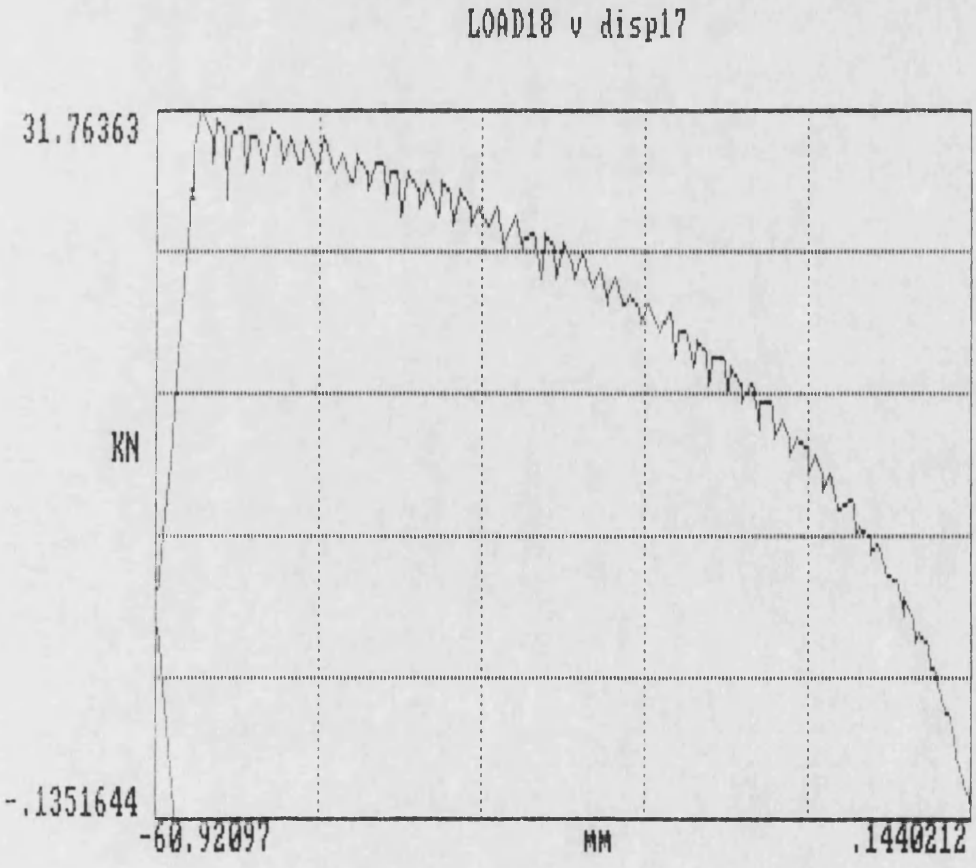
Angle of friction determined from; $\sin \phi = \dfrac{\sigma_1 - \sigma_3}{\sigma_1 + \sigma_3}$

Sample volume = 0.017 m^3,

Original sample height = 335mm,

Cross - sectional area at 10% strain = 0.0563 m^2


LOAD18 v Time
100
KN
0
0
Secs
500


LOAD18 v disp17
31.76363
KN
-.1351644
-60.92097
MM
.1440212

Number of Readings 286 No. Columns 4
Date Task Started 01/01/83 Time Task Started 00-16-27

	Time Secs 1	disp17 mm 2	LOAD18 KN 3	LOAD NON 4
0	0.0	0.144	0.225	5
1	2.0	0.144	0.225	4
2	4.0	0.144	0.225	4
3	6.0	0.144	0.225	4
4	8.0	0.144	0.225	4
5	10.0	0.144	0.225	4
6	12.0	0.144	0.225	4
7	14.0	0.144	0.225	3
8	16.0	0.144	0.225	4
9	18.0	0.144	0.225	5
10	20.0	0.144	0.360	7
11	22.0	-1.080	2.568	43
12	24.0	-1.296	3.785	64
13	26.0	-1.656	4.641	78
14	28.0	-1.728	4.641	78
15	30.0	-2.232	6.037	101
16	32.0	-2.664	6.578	110
17	34.0	-2.808	6.758	114
18	36.0	-3.312	7.794	130
19	38.0	-3.817	8.290	138
20	40.0	-3.889	7.840	130
21	42.0	-4.249	9.191	154
22	44.0	-4.825	9.642	161
23	46.0	-4.969	9.056	152
24	48.0	-5.401	10.543	177
25	50.0	-6.121	10.858	181
26	52.0	-6.193	10.948	184
27	54.0	-6.841	12.030	201
28	56.0	-7.345	11.714	195
29	58.0	-7.489	12.796	215
30	60.0	-8.209	13.201	221
31	62.0	-8.497	12.660	211
32	64.0	-8.857	14.147	237
33	66.0	-9.649	13.922	231
34	68.0	-9.793	13.742	230
35	70.0	-10.370	15.274	255
36	72.0	-10.874	14.778	246
37	74.0	-11.018	15.409	258
38	76.0	-11.594	16.130	270
39	78.0	-12.026	15.589	260
40	80.0	-12.170	16.445	276
41	82.0	-12.818	16.896	281
42	84.0	-13.322	16.355	272
43	86.0	-13.394	16.941	285
44	88.0	-14.114	17.707	297
45	90.0	-14.546	16.941	282
46	92.0	-14.762	18.427	310
47	94.0	-15.554	18.698	312
48	96.0	-15.770	17.571	293
49	98.0	-16.346	19.374	324
50	100.0	-17.067	18.427	306

Number of Readings 286 No. Columns 4
Date Task Started 01/01/83 Time Task Started 00-16-27

	Time Secs 1	disp17 mm 2	LOAD18 KN 3	LOAD NON 4	
51	102.0	-17.139	19.329	324	
52	104.0	-17.931	20.004	334	
53	106.0	-18.291	18.923	314	
54	108.0	-18.507	20.500	344	
55	110.0	-19.227	20.545	343	
56	112.0	-19.515	19.554	325	
57	114.0	-19.803	21.176	353	
58	116.0	-20.523	21.446	356	
59	118.0	-20.811	20.139	334	
60	120.0	-21.171	21.897	364	
61	122.0	-21.891	21.761	361	
62	124.0	-22.035	20.635	342	
63	126.0	-22.467	22.663	377	
64	128.0	-23.259	21.761	360	
65	130.0	-23.403	22.347	372	
66	132.0	-24.052	23.023	383	
67	134.0	-24.484	22.122	366	
68	136.0	-24.700	23.113	385	
69	138.0	-25.276	23.564	390	
70	140.0	-25.780	22.798	377	
71	142.0	-25.924	23.113	384	
72	144.0	-26.572	24.014	397	
73	146.0	-27.004	23.203	383	
74	148.0	-27.148	22.978	382	
75	150.0	-27.724	24.735	409	
76	152.0	-28.300	23.699	391	
77	154.0	-28.444	24.059	399	
78	156.0	-29.092	25.186	417	
79	158.0	-29.596	24.104	398	
80	160.0	-29.812	25.096	417	
81	162.0	-30.460	25.636	423	
82	164.0	-30.893	24.239	400	
83	166.0	-31.109	25.726	426	
84	168.0	-31.901	26.087	432	
85	170.0	-32.189	24.375	402	
86	172.0	-32.693	26.357	435	
87	174.0	-33.341	25.907	426	10% strain
88	176.0	-33.485	25.411	420	
89	178.0	-34.133	27.033	446	
90	180.0	-34.709	25.907	425	
91	182.0	-34.781	25.456	421	
92	184.0	-35.357	27.213	448	
93	186.0	-35.933	26.672	437	
94	188.0	-36.077	26.627	439	
95	190.0	-36.725	27.574	453	
96	192.0	-37.229	26.672	437	
97	194.0	-37.374	27.213	451	
98	196.0	-38.166	28.204	464	
99	198.0	-38.598	26.672	438	
100	200.0	-38.886	28.294	467	
101	202.0	-39.534	28.430	467	

Number of Readings 286 No. Columns 4
Date Task Started 01/01/83 Time Task Started 00-16-27

	Time Secs 1	displ7 mm 2	LOAD18 KN 3	LOAD NON 4	
102	204.0	-39.894	26.853	440	
103	206.0	-39.966	27.709	457	
104	208.0	-40.686	28.610	470	
105	210.0	-41.118	27.438	449	
106	212.0	-41.334	28.249	467	
107	214.0	-41.982	28.880	474	
108	216.0	-42.414	28.159	460	
109	218.0	-42.558	27.168	445	
110	220.0	-42.846	29.060	477	
111	222.0	-43.494	29.150	477	
112	224.0	-43.782	27.664	453	
113	226.0	-44.070	29.376	482	
114	228.0	-44.647	29.376	481	
115	230.0	-45.007	28.024	457	
116	232.0	-45.223	29.060	478	
117	234.0	-45.799	29.601	485	
118	236.0	-46.303	28.520	465	
119	238.0	-46.447	28.610	471	
120	240.0	-46.951	29.961	490	
121	242.0	-47.527	28.970	472	
122	244.0	-47.743	29.286	481	
123	246.0	-48.391	30.412	497	peak
124	248.0	-48.895	29.060	474	
125	250.0	-49.039	29.376	481	
126	252.0	-49.687	30.727	502	
127	254.0	-50.191	29.241	477	
128	256.0	-50.335	29.556	484	
129	258.0	-50.984	30.727	500	
130	260.0	-51.488	29.466	480	
131	262.0	-51.704	30.412	497	
132	264.0	-52.424	30.863	503	
133	266.0	-52.856	29.511	480	
134	268.0	-52.928	29.015	473	
135	270.0	-53.360	30.727	501	
136	272.0	-54.008	30.592	496	
137	274.0	-54.224	29.060	473	
138	276.0	-54.512	30.772	502	
139	278.0	-55.232	30.727	499	
140	280.0	-55.520	29.331	476	
141	282.0	-55.592	28.655	467	
142	284.0	-55.664	28.339	462	
143	286.0	-55.664	28.114	459	
144	288.0	-55.664	27.979	456	
145	290.0	-55.664	27.869	455	
146	292.0	-55.736	27.799	454	
147	294.0	-55.880	[illegible]	[illegible]	
148	296.0	-56.456	[illegible]	[illegible]	
149	298.0	[illegible]	[illegible]	481	
150	[illegible]	-56.888	30.502	499	
151	302.0	-57.680	31.764	516	
152	304.0	-58.041	30.052	488	

Number of Readings 286 No. Columns 4
Date Task Started 01/01/83 Time Task Started 00-16-27

	Time Secs 1	displ7 mm 2	LOAD18 KN 3	LOAD NON 4
153	306.0	-58.113	29.331	476
154	308.0	-58.185	28.925	471
155	310.0	-58.185	28.745	467
156	312.0	-58.185	28.565	465
157	314.0	-58.185	28.430	465
158	316.0	-58.257	28.385	462
159	318.0	-58.257	28.294	462
160	320.0	-58.257	28.249	460
161	322.0	-58.257	28.159	460
162	324.0	-58.257	28.159	459
163	326.0	-58.257	28.114	458
164	328.0	-58.257	28.069	457
165	330.0	-58.329	28.024	457
166	332.0	-58.257	27.979	456
167	334.0	-58.329	27.934	456
168	336.0	-58.257	27.934	456
169	338.0	-58.257	27.889	454
170	340.0	-58.329	27.889	454
171	342.0	-58.329	27.889	454
172	344.0	-58.329	27.844	455
173	346.0	-58.329	27.799	454
174	348.0	-58.329	27.799	454
175	350.0	-58.329	27.799	453
176	352.0	-58.329	27.754	453
177	354.0	-58.329	27.754	453
178	356.0	-58.329	27.709	453
179	358.0	-58.329	27.709	451
180	360.0	-58.329	27.709	452
181	362.0	-58.329	27.664	451
182	364.0	-58.329	27.664	450
183	366.0	-58.329	27.664	450
184	368.0	-58.329	27.619	451
185	370.0	-58.329	27.619	451
186	372.0	-58.329	27.619	450
187	374.0	-58.329	27.574	450
188	376.0	-58.329	27.574	449
189	378.0	-58.329	27.574	449
190	380.0	-58.329	27.528	449
191	382.0	-58.329	27.528	449
192	384.0	-58.329	27.528	449
193	386.0	-58.401	27.483	449
194	388.0	-58.329	27.483	449
195	390.0	-58.329	27.483	448
196	392.0	-58.329	27.483	447
197	394.0	-58.329	27.438	448
198	396.0	-58.329	27.438	448
199	398.0	-58.329	27.438	447
200	400.0	-58.401	27.438	447
201	402.0	-59.193	20.950	337
202	404.0	-59.841	16.220	264
203	406.0	-60.273	13.066	214

Number of Readings 286 No. Columns 4
Date Task Started 01/01/83 Time Task Started 00-16-27

	Time Secs 1	disp17 mm 2	LOAD18 KN 3	LOAD NON 4
204	408.0	-60.633	10.948	180
205	410.0	-60.921	9.326	154
206	412.0	-59.409	-0.135	-1
207	414.0	-59.409	-0.090	1
208	416.0	-59.409	-0.090	1
209	418.0	-59.409	-0.090	0
210	420.0	-59.409	-0.090	1
211	422.0	-59.409	-0.090	1
212	424.0	-59.409	-0.090	0
213	426.0	-59.409	-0.045	0
214	428.0	-59.409	-0.090	1
215	430.0	-59.337	-0.090	0
216	432.0	-59.337	-0.090	1
217	434.0	-59.337	-0.090	0
218	436.0	-59.409	-0.045	1
219	438.0	-59.409	-0.045	1
220	440.0	-59.409	-0.045	0
221	442.0	-59.409	-0.045	0
222	444.0	-59.409	-0.045	1
223	446.0	-59.409	-0.045	1
224	448.0	-59.409	-0.045	-0
225	450.0	-59.337	-0.045	1
226	452.0	-59.337	-0.045	0
227	454.0	-59.337	-0.090	-0
228	456.0	-59.409	-0.045	0
229	458.0	-59.337	-0.045	0
230	460.0	-59.337	-0.045	-0
231	462.0	-59.337	-0.045	-0
232	464.0	-59.337	-0.045	1
233	466.0	-59.337	-0.045	1
234	468.0	-59.337	-0.045	0
235	470.0	-59.337	-0.045	0
236	472.0	-59.337	-0.045	1
237	474.0	-59.337	-0.045	1
238	476.0	-59.337	-0.045	1
239	478.0	-59.337	-0.045	1
240	480.0	-59.337	-0.045	1
241	482.0	-59.337	-0.045	1
242	484.0	-59.337	-0.045	1
243	486.0	-59.337	-0.045	-0
244	488.0	-59.337	-0.045	1
245	490.0	-59.337	-0.045	1
246	492.0	-59.409	-0.045	0
247	494.0	-59.337	-0.045	1
248	496.0	-59.409	-0.045	1
249	498.0	-59.337	-0.045	1
250	500.0	-59.337	-0.045	1
251	502.0	-59.337	-0.045	1
252	504.0	-59.337	-0.045	1
253	506.0	-59.337	-0.045	0
254	508.0	-59.337	-0.045	1

Number of Readings 286 No. Columns 4
Date Task Started 01/01/83 Time Task Started 00-16-27

	Time Secs 1	disp17 mm 2	LOAD18 KN 3	LOAD NON 4
255	510.0	-59.337	-0.045	0
256	512.0	-59.337	-0.045	0
257	514.0	-59.337	-0.045	1
258	516.0	-59.337	-0.045	1
259	518.0	-59.337	-0.045	0
260	520.0	-59.337	-0.045	1
261	522.0	-59.337	-0.045	2
262	524.0	-59.337	-0.045	1
263	526.0	-59.337	-0.045	1
264	528.0	-59.337	-0.045	1
265	530.0	-59.337	-0.045	1
266	532.0	-59.337	-0.045	0
267	534.0	-59.337	-0.045	1
268	536.0	-59.337	-0.045	0
269	538.0	-59.337	-0.045	0
270	540.0	-59.337	-0.045	1
271	542.0	-59.337	-0.045	0
272	544.0	-59.337	-0.045	1
273	546.0	-59.337	-0.045	0
274	548.0	-59.337	-0.045	1
275	550.0	-59.337	-0.045	1
276	552.0	-59.337	-0.045	1
277	554.0	-59.337	-0.045	0
278	556.0	-59.337	-0.045	1
279	558.0	-59.337	-0.045	0
280	560.0	-59.337	-0.045	1
281	562.0	-59.337	-0.045	1
282	564.0	-59.337	-0.045	1
283	566.0	-59.337	-0.045	0
284	568.0	-59.337	0.000	0
285	570.0	-59.337	-0.045	1
286	572.0	-59.337	-0.045	1

CALCULATION SHEET FOR TEST .... Triax 11

Peak axial load difference [kN] = 36.22 ⎫ combination giving peak stress

Axial compression [mm] = 43.0 ⎭

Cross - sectional area [m^2] = 0.0582

Stress difference, $\sigma_1 - \sigma_3$ [kN/m^2] = 622

Cell pressure, σ_3 [kN/m^2] = 100

Angle of friction, ϕ = **49.20°**

Axial load difference at 10% axial strain [kN] = 33.0

Stress difference, $\sigma_1 - \sigma_3$ [kN/m^2] = 586

Cell pressure, σ_3 [kN/m^2] = 100

Angle of friction, ϕ = **48.27°**

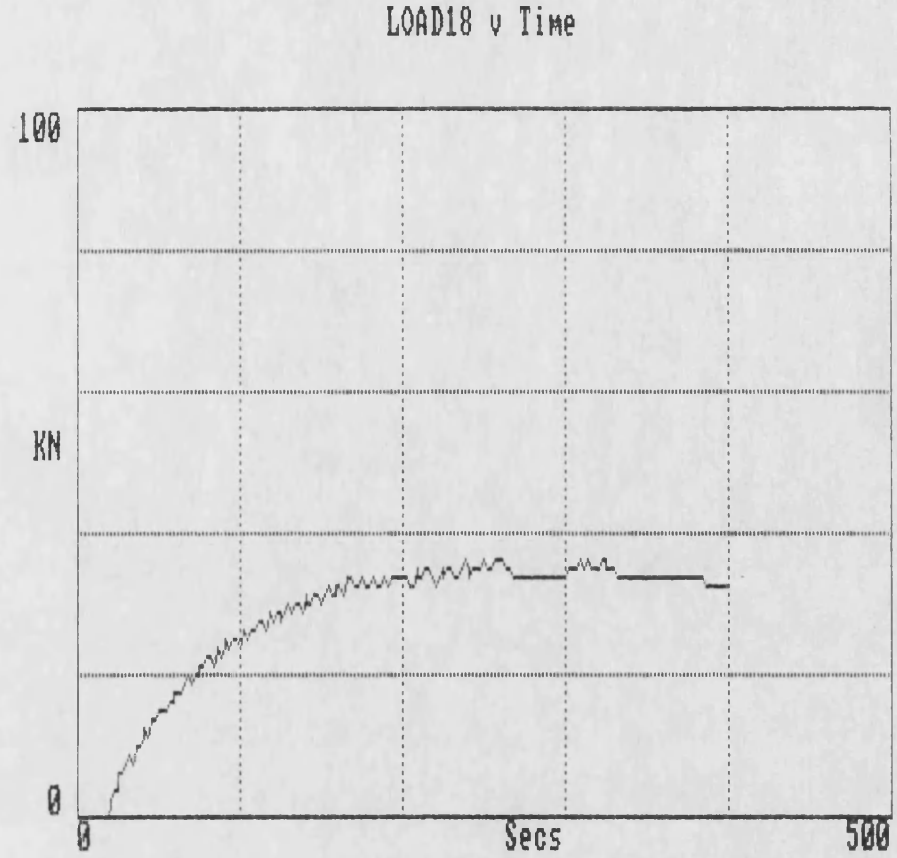
$$\text{Cross - sectional area} = \frac{\text{Sample volume}}{\text{Orig. height - axial comp.}}$$

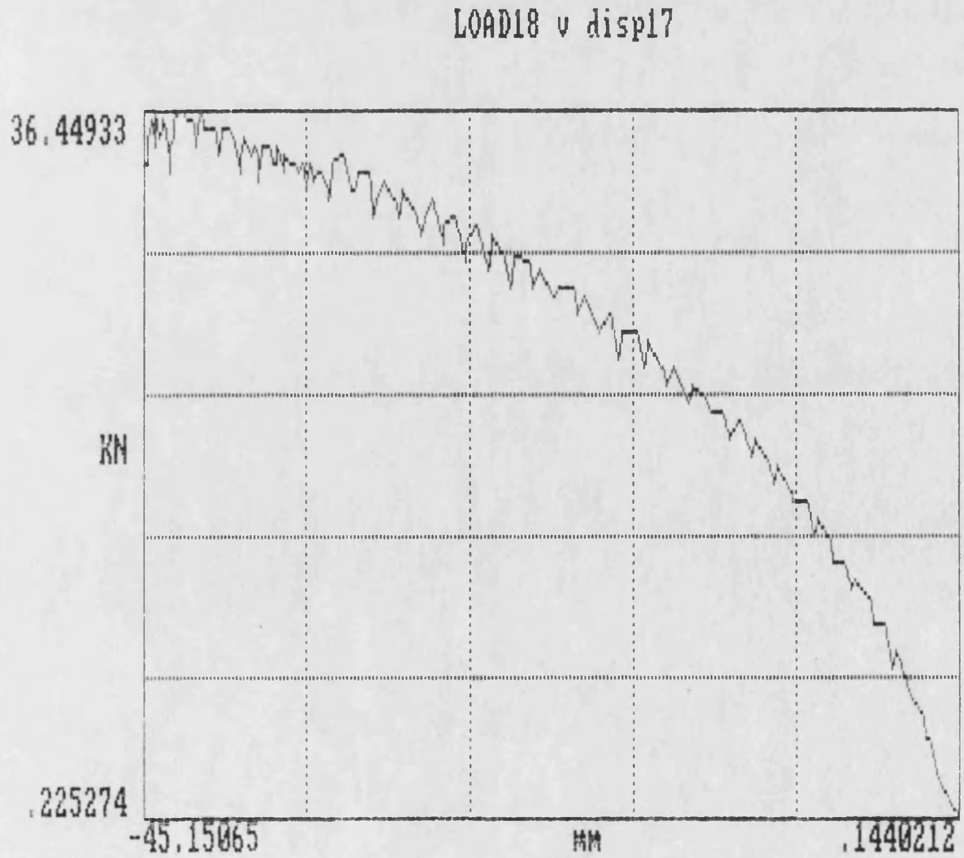
$$\text{Angle of friction determined from; } \sin\phi = \frac{\sigma_1 - \sigma_3}{\sigma_1 + \sigma_3}$$

Sample volume = 0.017 m^3,

Original sample height = 335mm,

Cross - sectional area at 10% strain = 0.0563 m^2


LOAD18 v Time
100
KN
0
0
Secs
500


LOAD18 v disp17
36.44933
KN
.225274
-45.15065
MM
.1440212

Number of Readings 200 No. Columns 4
Date Task Started 01/01/83 Time Task Started 00-04-40

	Time Secs 1	displ7 mm 2	LOAD18 KN 3	LOAD NON 4
0	0.0	0.144	0.225	4
1	2.0	0.144	0.225	4
2	4.0	0.144	0.225	5
3	6.0	0.144	0.225	4
4	8.0	0.144	0.225	4
5	10.0	0.144	0.225	4
6	12.0	0.144	0.225	5
7	14.0	0.144	0.225	4
8	16.0	0.144	0.225	5
9	18.0	0.144	0.315	5
10	20.0	-1.008	2.613	46
11	22.0	-1.440	4.235	71
12	24.0	-1.728	4.370	73
13	26.0	-1.944	5.677	97
14	28.0	-2.592	6.578	110
15	30.0	-2.736	7.119	121
16	32.0	-3.457	8.696	147
17	34.0	-3.601	8.110	136
18	36.0	-4.033	10.047	169
19	38.0	-4.537	10.047	167
20	40.0	-4.825	11.354	192
21	42.0	-5.617	12.255	206
22	44.0	-5.761	11.804	198
23	46.0	-6.337	13.561	228
24	48.0	-6.769	13.381	222
25	50.0	-6.985	14.598	246
26	52.0	-7.633	15.409	257
27	54.0	-7.921	14.598	243
28	56.0	-8.353	16.445	276
29	58.0	-9.073	16.535	276
30	60.0	-9.217	17.166	289
31	62.0	-9.937	18.112	303
32	64.0	-10.226	17.301	288
33	66.0	-10.514	18.788	314
34	68.0	-11.234	19.554	326
35	70.0	-11.450	18.608	311
36	72.0	-12.098	20.410	340
37	74.0	-12.602	19.599	324
38	76.0	-12.962	21.176	352
39	78.0	-13.682	20.905	345
40	80.0	-13.970	21.897	366
41	82.0	-14.690	22.437	372
42	84.0	-14.978	21.356	354
43	86.0	-15.698	23.519	391
44	88.0	-16.202	22.572	373
45	90.0	-16.346	23.519	390
46	92.0	-17.067	24.555	406
47	94.0	-17.427	23.248	384
48	96.0	-17.715	25.005	415
49	98.0	-18.507	25.276	418
50	100.0	-18.723	23.879	393

Number of Readings 200 No. Columns 4
Date Task Started 01/01/83 Time Task Started 00-04-40

	Time Secs 1	displ7 mm 2	LOAD18 KN 3	LOAD NON 4
51	102.0	-19.227	25.952	430
52	104.0	-19.803	25.276	416
53	106.0	-19.947	25.771	428
54	108.0	-20.595	26.718	441
55	110.0	-21.027	25.861	426
56	112.0	-21.315	27.303	451
57	114.0	-22.179	27.483	451
58	116.0	-22.323	26.853	444
59	118.0	-23.043	28.159	465
60	120.0	-23.475	27.258	447
61	122.0	-23.764	28.565	470
62	124.0	-24.484	29.060	477
63	126.0	-24.772	27.619	454
64	128.0	-25.132	29.331	484
65	130.0	-25.852	30.097	494
66	132.0	-25.996	28.294	463
67	134.0	-26.644	30.457	500
68	136.0	-27.148	29.826	488
69	138.0	-27.292	28.655	470
70	140.0	-27.868	31.133	512
71	142.0	-28.444	30.502	499
72	144.0	-28.516	29.466	483
73	146.0	-29.020	31.764	522
74	148.0	-29.596	31.223	510
75	150.0	-29.740	30.007	491
76	152.0	-30.028	31.674	520
77	154.0	-30.677	32.575	534
78	156.0	-30.965	30.817	503
79	158.0	-31.181	31.854	523
80	160.0	-31.685	32.665	534
81	162.0	-32.189	32.124	525
82	164.0	-32.333	31.043	508
83	166.0	-32.693	33.205	543
84	168.0	-33.125	33.250	544 10% strain
85	170.0	-33.485	32.259	528
86	172.0	-33.629	32.530	532
87	174.0	-34.133	33.971	557
88	176.0	-34.709	33.611	549
89	178.0	-34.853	32.124	524
90	180.0	-34.925	32.485	532
91	182.0	-35.213	33.431	547
92	184.0	-35.501	33.115	540
93	186.0	-35.645	32.800	536
94	188.0	-35.861	33.566	548
95	190.0	-36.005	32.800	535
96	192.0	-36.149	32.169	526
97	194.0	-36.293	33.521	548
98	196.0	-36.437	33.431	546
99	198.0	-36.653	33.836	552
100	200.0	-36.869	33.881	553
101	202.0	-37.229	34.106	557

Number of Readings 200 No. Columns 4
Date Task Started 01/01/83 Time Task Started 00-04-40

	Time Secs 1	disp17 mm 2	LOAD18 KN 3	LOAD NON 4	
102	204.0	-37.301	33.070	540	
103	206.0	-37.374	33.070	541	
104	208.0	-37.662	34.467	562	
105	210.0	-37.806	33.926	554	
106	212.0	-37.950	33.836	554	
107	214.0	-38.166	34.602	565	
108	216.0	-38.526	34.647	564	
109	218.0	-38.670	33.476	546	
110	220.0	-38.670	33.025	538	
111	222.0	-38.742	34.061	557	
112	224.0	-38.886	34.422	562	
113	226.0	-39.102	34.061	554	
114	228.0	-39.318	34.782	566	
115	230.0	-39.534	35.143	574	
116	232.0	-39.822	34.061	554	
117	234.0	-39.894	33.431	545	
118	236.0	-40.110	35.278	575	
119	238.0	-40.470	35.638	581	
120	240.0	-40.902	35.593	579	
121	242.0	-41.046	34.242	557	
122	244.0	-41.190	35.503	580	
123	246.0	-41.478	35.458	577	
124	248.0	-41.766	35.413	577	
125	250.0	-41.982	36.224	591	
126	252.0	-42.270	35.008	568	
127	254.0	-42.342	34.647	564	
128	256.0	-42.486	35.999	586	
129	258.0	-42.774	36.044	587	
130	260.0	-43.134	36.449	593	peak
131	262.0	-43.422	35.954	584	
132	264.0	-43.566	35.008	570	
133	266.0	-43.638	34.557	562	
134	268.0	-43.638	34.332	559	
135	270.0	-43.638	34.106	555	
136	272.0	-43.710	33.971	552	
137	274.0	-43.710	33.836	552	
138	276.0	-43.710	33.746	550	
139	278.0	-43.710	33.701	549	
140	280.0	-43.710	33.611	547	
141	282.0	-43.710	33.566	547	
142	284.0	-43.710	33.476	546	
143	286.0	-43.782	33.431	545	
144	288.0	-43.782	33.386	545	
145	290.0	-43.782	33.341	544	
146	292.0	-43.782	33.296	543	
147	294.0	-43.782	33.250	542	
148	296.0	-43.782	33.250	542	
149	298.0	-43.782	33.205	541	
150	300.0	-43.782	33.926	555	
151	302.0	-43.854	35.143	572	
152	304.0	-43.854	35.008	571	

Number of Readings 200 No. Columns 4
Date Task Started 01/01/83 Time Task Started 00-04-40

	Time Secs 1	disp17 mm 2	LOAD18 KN 3	LOAD NON 4
153	306.0	-43.926	35.548	578
154	308.0	-44.070	35.999	586
155	310.0	-44.215	35.728	581
156	312.0	-44.287	35.098	571
157	314.0	-44.431	36.224	590
158	316.0	-44.503	35.368	575
159	318.0	-44.575	34.917	568
160	320.0	-44.575	34.647	564
161	322.0	-44.647	36.044	587
162	324.0	-44.791	35.774	581
163	326.0	-44.863	35.098	571
164	328.0	-44.935	34.737	565
165	330.0	-44.935	34.512	562
166	332.0	-44.935	34.332	559
167	334.0	-44.935	34.197	557
168	336.0	-45.007	34.106	555
169	338.0	-45.007	34.016	553
170	340.0	-45.007	33.926	552
171	342.0	-45.007	33.836	551
172	344.0	-45.007	33.791	550
173	346.0	-45.007	33.701	550
174	348.0	-45.007	33.701	549
175	350.0	-45.079	33.611	548
176	352.0	-45.079	33.566	546
177	354.0	-45.079	33.566	547
178	356.0	-45.079	33.521	546
179	358.0	-45.079	33.476	544
180	360.0	-45.079	33.431	545
181	362.0	-45.079	33.386	544
182	364.0	-45.079	33.386	545
183	366.0	-45.079	33.341	544
184	368.0	-45.079	33.341	542
185	370.0	-45.079	33.341	543
186	372.0	-45.079	33.296	543
187	374.0	-45.079	33.250	542
188	376.0	-45.079	33.250	542
189	378.0	-45.079	33.205	541
190	380.0	-45.079	33.205	542
191	382.0	-45.151	33.160	541
192	384.0	-45.079	33.160	540
193	386.0	-45.151	33.115	540
194	388.0	-45.151	33.115	539
195	390.0	-45.079	33.070	539
196	392.0	-45.079	33.070	538
197	394.0	-45.079	33.070	540
198	396.0	-45.151	33.025	539
199	398.0	-45.151	33.025	538
200	400.0	-45.079	33.025	537

CALCULATION SHEET FOR TEST .... Triax 12

Load response jump. Adjusted peak used.

Peak axial load difference [kN] = 30
Axial compression [mm] = 35
} combination giving peak stress

Cross - sectional area [m^2] = 0.0567

Stress difference, $\sigma_1 - \sigma_3$ [kN/m^2] = 529

Cell pressure, σ_3 [kN/m^2] = 100

Angle of friction, ϕ = **46.53°**

Axial load difference at 10% axial strain [kN] = 27.44

Stress difference, $\sigma_1 - \sigma_3$ [kN/m^2] = 487

Cell pressure, σ_3 [kN/m^2] = 100

Angle of friction, ϕ = **45.19°**

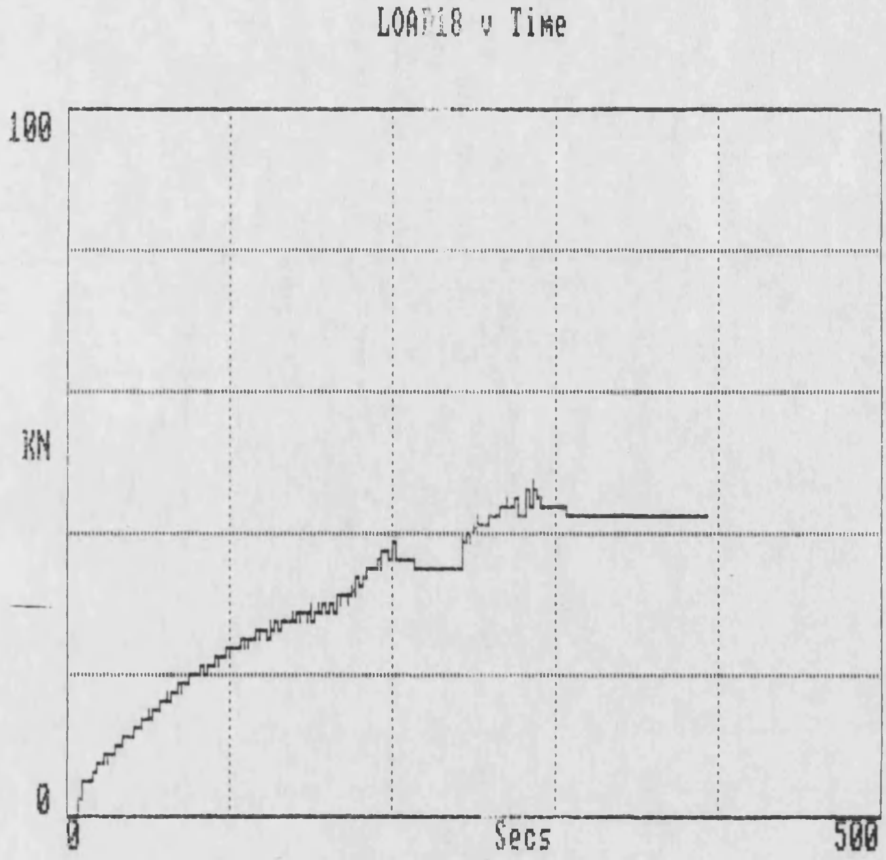
$$\text{Cross - sectional area} = \frac{\text{Sample volume}}{\text{Orig. height - axial comp.}}$$

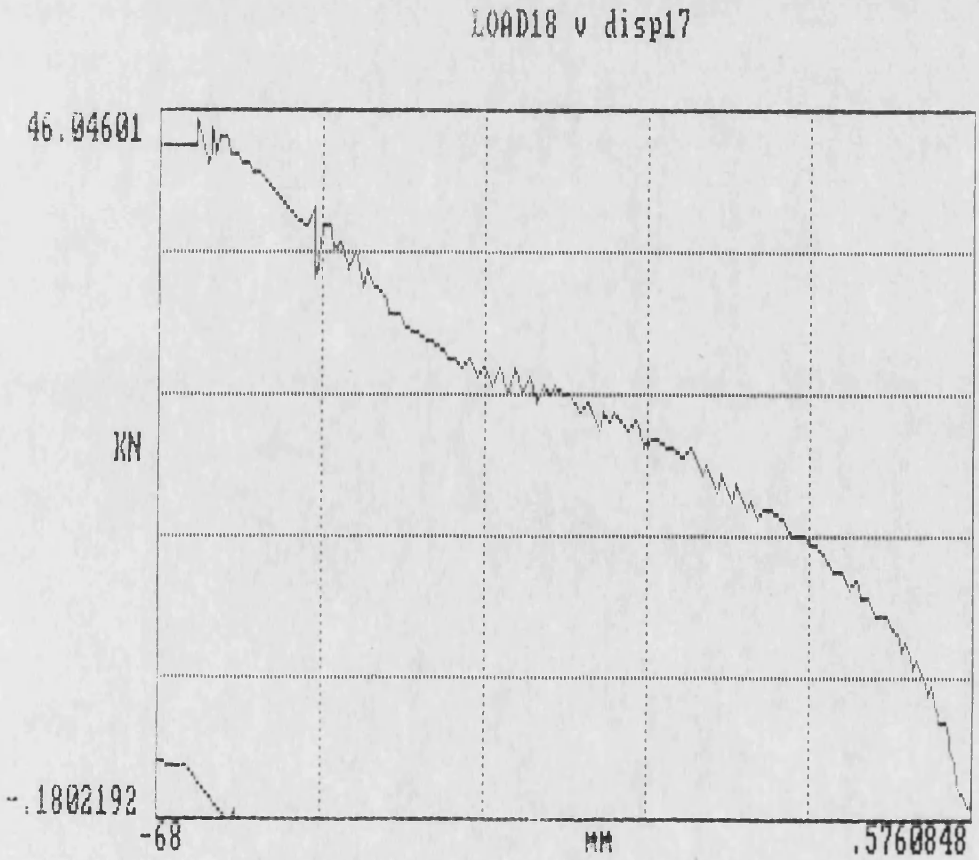
$$\text{Angle of friction determined from; } \sin\phi = \frac{\sigma_1 - \sigma_3}{\sigma_1 + \sigma_3}$$

Sample volume = 0.017 m^3,

Original sample height = 335mm,

Cross - sectional area at 10% strain = 0.0563 m^2


LOAD18 v Time
100
KN
0
0
Secs
500


LOAD18 v disp17
46.04601
KN
-.1802192
-68
MM
.5760848

Number of Readings 278 No. Columns 4
Date Task Started 01/01/83 Time Task Started 03-16-28

	Time Secs 1	displ7 mm 2	LOAD18 KN 3	LOAD NON 4
0	0.0	0.576	0.225	4
1	2.0	0.576	0.225	4
2	4.0	0.576	0.225	3
3	6.0	0.576	0.225	4
4	8.0	0.576	0.225	3
5	10.0	0.576	0.225	5
6	12.0	0.576	0.225	4
7	14.0	0.504	0.315	5
8	16.0	-0.648	2.298	41
9	18.0	-1.080	3.920	67
10	20.0	-1.224	4.460	74
11	22.0	-1.368	5.226	90
12	24.0	-1.728	6.082	104
13	26.0	-2.088	6.263	104
14	28.0	-2.160	6.983	118
15	30.0	-2.448	7.524	126
16	32.0	-2.952	8.380	140
17	34.0	-3.168	7.975	133
18	36.0	-3.384	9.056	151
19	38.0	-3.745	9.597	160
20	40.0	-4.105	10.137	168
21	42.0	-4.321	9.777	163
22	44.0	-4.609	10.813	180
23	46.0	-5.113	11.264	187
24	48.0	-5.401	10.903	181
25	50.0	-5.689	12.075	201
26	52.0	-6.409	12.390	206
27	54.0	-6.697	13.111	219
28	56.0	-7.633	13.381	222
29	58.0	-8.065	14.147	235
30	60.0	-8.641	14.057	232
31	62.0	-9.145	15.229	253
32	64.0	-9.793	14.913	247
33	66.0	-10.442	16.130	267
34	68.0	-11.018	15.769	260
35	70.0	-11.882	17.166	285
36	72.0	-12.386	17.481	290
37	74.0	-12.962	17.661	292
38	76.0	-13.394	[illegible]	298
39	78.0	-14.042	18.292	303
40	80.0	-14.402	18.518	306
41	82.0	-14.978	18.833	310
42	84.0	-15.410	19.374	320
43	86.0	-16.202	19.869	328
44	88.0	-16.778	20.165	334
45	90.0	-17.355	19.644	324
46	92.0	-18.003	20.770	344
47	94.0	-18.507	20.185	332
48	96.0	-19.227	21.716	358
49	98.0	-19.803	20.815	342
50	100.0	-20.595	22.212	366

Number of Readings 278 No. Columns 4
Date Task Started 01/01/83 Time Task Started 03-16-28

	Time Secs 1	displ7 mm 2	LOAD18 KN 3	LOAD NON 4	
51	102.0	-21.027	21.266	349	
52	104.0	-21.891	22.843	376	
53	106.0	-22.323	22.257	365	
54	108.0	-23.259	23.879	392	
55	110.0	-23.691	23.609	389	
56	112.0	-24.556	24.194	396	
57	114.0	-24.916	23.969	393	
58	116.0	-25.852	24.825	407	
59	118.0	-26.284	24.690	405	
60	120.0	-27.220	24.285	397	
61	122.0	-27.796	25.591	420	
62	124.0	-28.444	25.231	412	
63	126.0	-29.524	26.312	430	
64	128.0	-29.884	25.771	422	
65	130.0	-30.532	26.492	433	
66	132.0	-31.037	25.186	410	
67	134.0	-31.757	26.898	439	
68	136.0	-32.333	26.402	432	
69	138.0	-33.269	27.664	451	10%
70	140.0	-33.773	27.528	449	
71	142.0	-34.565	28.024	457	
72	144.0	-34.925	27.619	451	
73	146.0	-35.645	27.979	454	
74	148.0	-36.077	27.078	439	
75	150.0	-36.797	28.655	466	
76	152.0	-37.374	27.438	444	
77	154.0	-38.166	29.015	471	
78	156.0	-38.670	27.664	448	
79	158.0	-39.390	29.286	476	
80	160.0	-39.966	27.934	452	
81	162.0	-40.470	29.286	476	
82	164.0	-41.190	28.655	464	
83	166.0	-41.838	29.601	480	
84	168.0	-42.558	29.060	469	
85	170.0	-42.918	29.826	484	
86	172.0	-43.710	29.916	483	
87	174.0	-44.070	30.277	492	
88	176.0	-44.863	30.953	502	
89	178.0	-45.295	31.088	504	
90	180.0	-46.087	31.583	512	
91	182.0	-46.519	31.809	516	
92	184.0	-47.383	32.124	518	
93	186.0	-47.743	32.530	526	
94	188.0	-48.607	32.890	530	
95	190.0	-49.039	33.836	549	
96	192.0	-49.687	34.287	554	
97	194.0	-49.975	34.692	561	
98	196.0	-50.623	35.368	571	
99	198.0	-50.984	34.737	561	
100	200.0	-51.632	36.675	593	
101	202.0	-52.208	35.458	570	

Number of Readings 278 No. Columns 4
Date Task Started 01/01/83 Time Task Started 03-16-28

	Time Secs 1	displ7 mm 2	LOAD18 KN 3	LOAD NON 4
102	204.0	-52.784	37.531	607
103	206.0	-53.360	36.630	589
104	208.0	-53.720	38.252	618
105	210.0	-54.440	38.342	616
106	212.0	-54.656	36.765	591
107	214.0	-54.656	36.269	585
108	216.0	-54.728	36.044	581
109	218.0	-54.728	35.864	578
110	220.0	-54.728	35.728	576
111	222.0	-54.728	35.593	574
112	224.0	-54.728	35.503	573
113	226.0	-54.800	35.458	572
114	228.0	-54.728	35.368	571
115	230.0	-54.800	35.323	570
116	232.0	-54.800	35.278	570
117	234.0	-54.800	35.233	568
118	236.0	-54.800	35.188	568
119	238.0	-54.800	35.143	568
120	240.0	-54.800	35.143	566
121	242.0	-54.800	35.098	566
122	244.0	-54.800	35.053	565
123	246.0	-54.800	35.053	566
124	248.0	-54.800	35.008	565
125	250.0	-54.800	35.008	564
126	252.0	-54.944	39.603	645
127	254.0	-55.664	38.252	615
128	256.0	-56.312	39.108	629
129	258.0	-57.104	39.468	634
130	260.0	-57.752	40.009	643
131	262.0	-58.401	40.775	656
132	264.0	-58.977	41.405	666
133	266.0	-59.625	41.766	672
134	268.0	-60.057	42.081	676
135	270.0	-60.489	42.352	680
136	272.0	-60.993	42.667	686
137	274.0	-61.497	43.253	695
138	276.0	-62.001	43.253	695
139	278.0	-62.505	44.289	713
140	280.0	-63.009	44.199	710
141	282.0	-63.297	43.162	692
142	284.0	-63.585	44.875	721
143	286.0	-63.729	43.253	694
144	288.0	-63.801	42.712	686
145	290.0	-63.873	42.442	682
146	292.0	-64.810	45.460	729
147	294.0	-65.026	43.973	706
148	296.0	-589.911	46.046	736
149	298.0	-589.911	45.190	727
150	300.0	-589.911	44.334	712
151	302.0	-589.911	43.883	705
152	304.0	-589.911	43.748	702

Number of Readings 278 No. Columns 4
Date Task Started 01/01/83 Time Task Started 03-16-28

	Time Secs 1	displ7 mm 2	LOAD18 KN 3	LOAD NON 4
153	306.0	-589.911	43.568	699
154	308.0	-589.911	43.433	698
155	310.0	-589.911	43.343	696
156	312.0	-589.911	43.208	695
157	314.0	-589.911	43.162	693
158	316.0	-589.911	43.072	693
159	318.0	-589.911	43.027	691
160	320.0	-589.911	42.982	690
161	322.0	-589.911	42.892	690
162	324.0	-589.911	42.892	689
163	326.0	-589.911	42.847	688
164	328.0	-589.911	42.802	687
165	330.0	-589.911	42.757	687
166	332.0	-589.911	42.712	686
167	334.0	-589.911	42.712	685
168	336.0	-589.911	42.667	686
169	338.0	-589.911	42.667	685
170	340.0	-589.911	42.622	685
171	342.0	-589.911	42.622	685
172	344.0	-589.911	42.577	684
173	346.0	-589.911	42.532	684
174	348.0	-589.911	42.532	683
175	350.0	-589.911	42.532	684
176	352.0	-589.911	42.487	682
177	354.0	-589.911	42.442	683
178	356.0	-589.911	42.442	682
179	358.0	-589.911	42.442	682
180	360.0	-589.911	42.397	681
181	362.0	-589.911	42.397	681
182	364.0	-589.911	42.352	681
183	366.0	-589.911	42.352	680
184	368.0	-589.911	42.352	679
185	370.0	-589.911	42.306	680
186	372.0	-589.911	42.306	679
187	374.0	-589.911	42.306	680
188	376.0	-589.911	42.261	680
189	378.0	-589.911	42.261	680
190	380.0	-589.911	42.216	678
191	382.0	-589.911	42.216	678
192	384.0	-589.911	42.216	679
193	386.0	-589.911	42.171	678
194	388.0	-589.911	42.171	679
195	390.0	-589.911	42.171	677
196	392.0	-589.911	42.126	678
197	394.0	-589.911	42.126	677
198	396.0	-589.911	42.126	677
199	398.0	-589.911	42.081	677
200	400.0	-589.911	42.081	677
201	402.0	-589.911	42.081	676
202	404.0	-589.911	42.081	676
203	406.0	-589.911	42.036	677

Number of Readings 278 No. Columns 4
Date Task Started 01/01/83 Time Task Started 03-16-28

	Time Secs 1	disp17 mm 2	LOAD18 KN 3	LOAD NON 4
204	408.0	-589.911	42.036	675
205	410.0	-589.911	42.036	675
206	412.0	-589.911	42.036	675
207	414.0	-589.911	42.036	674
208	416.0	-589.911	41.991	675
209	418.0	-589.911	41.991	675
210	420.0	-589.911	41.991	675
211	422.0	-589.911	41.946	675
212	424.0	-589.911	41.946	675
213	426.0	-589.911	41.946	674
214	428.0	-589.911	41.946	674
215	430.0	-589.911	41.901	675
216	432.0	-589.911	41.901	674
217	434.0	-589.911	41.901	673
218	436.0	-589.911	41.901	674
219	438.0	-589.911	41.901	674
220	440.0	-589.911	41.856	674
221	442.0	-589.911	41.856	673
222	444.0	-589.911	41.856	673
223	446.0	-589.911	41.856	674
224	448.0	-589.911	41.856	672
225	450.0	-589.911	41.856	673
226	452.0	-589.911	41.811	672
227	454.0	-589.911	41.811	672
228	456.0	-589.911	41.811	672
229	458.0	-589.911	41.811	672
230	460.0	-589.911	41.766	672
231	462.0	-589.911	41.766	672
232	464.0	-589.911	41.766	673
233	466.0	-589.911	41.766	671
234	468.0	-589.911	41.766	672
235	470.0	-589.911	41.766	671
236	472.0	-589.911	41.721	672
237	474.0	-589.911	41.721	671
238	476.0	-589.911	41.721	671
239	478.0	-589.911	41.721	671
240	480.0	-589.911	41.721	671
241	482.0	-589.911	41.721	-0
242	484.0	-589.911	41.676	1
243	486.0	-65.386	3.379	2
244	488.0	-62.001	0.000	2
245	490.0	-61.497	0.090	2
246	492.0	-61.569	0.225	3
247	494.0	-61.569	0.180	3
248	496.0	-61.641	-0.090	3
249	498.0	-64.017	-0.180	2
250	500.0	-64.089	-0.180	2
251	502.0	-64.089	-0.135	2
252	504.0	-64.017	-0.135	2
253	506.0	-64.017	-0.135	2
254	508.0	-64.017	-0.135	2

Number of Readings 278 No. Columns 4
Date Task Started 01/01/83 Time Task Started 03-16-28

	Time Secs 1	disp17 mm 2	LOAD18 KN 3	LOAD NON 4
255	510.0	-63.945	-0.135	2
256	512.0	-64.017	-0.135	2
257	514.0	-63.945	-0.135	3
258	516.0	-64.017	-0.135	3
259	518.0	-64.017	-0.135	3
260	520.0	-64.017	-0.135	3
261	522.0	-64.017	-0.135	3
262	524.0	-64.017	-0.135	3
263	526.0	-64.017	-0.135	3
264	528.0	-64.017	-0.135	3
265	530.0	-64.017	-0.135	3
266	532.0	-64.017	-0.090	3
267	534.0	-64.017	-0.135	3
268	536.0	-64.017	-0.090	3
269	538.0	-64.017	-0.090	3
270	540.0	-64.017	-0.090	3
271	542.0	-64.017	-0.090	3
272	544.0	-64.017	-0.090	3
273	546.0	-64.017	-0.090	3
274	548.0	-64.017	-0.090	3
275	550.0	-64.017	-0.090	4
276	552.0	-63.945	-0.090	3
277	554.0	-64.017	-0.135	3
278	556.0	-63.945	-0.090	3

CALCULATION SHEET FOR TEST .... Triax 13

Peak axial load difference [kN] = 43.52
Axial compression [mm] = 51.56
combination giving peak stress

Cross - sectional area [m^2] = 0.060

Stress difference, $\sigma_1 - \sigma_3$ [kN/m^2] = 726

Cell pressure, σ_3 [kN/m^2] = 100

Angle of friction, ϕ = **51.62°**

Axial load difference at 10% axial strain [kN] = 26.94

Stress difference, $\sigma_1 - \sigma_3$ [kN/m^2] = 479

Cell pressure, σ_3 [kN/m^2] = 100

Angle of friction, ϕ = **44.85°**

$$\text{Cross - sectional area} = \frac{\text{Sample volume}}{\text{Orig. height - axial comp.}}$$

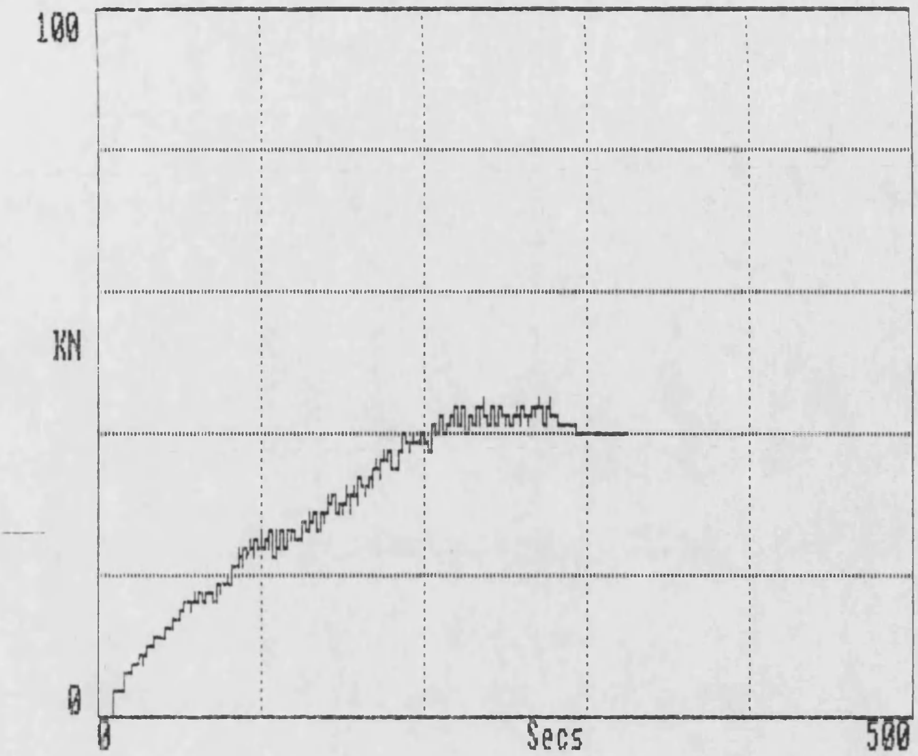
Angle of friction determined from; $\sin \phi = \dfrac{\sigma_1 - \sigma_3}{\sigma_1 + \sigma_3}$

Sample volume = 0.017 m^3,

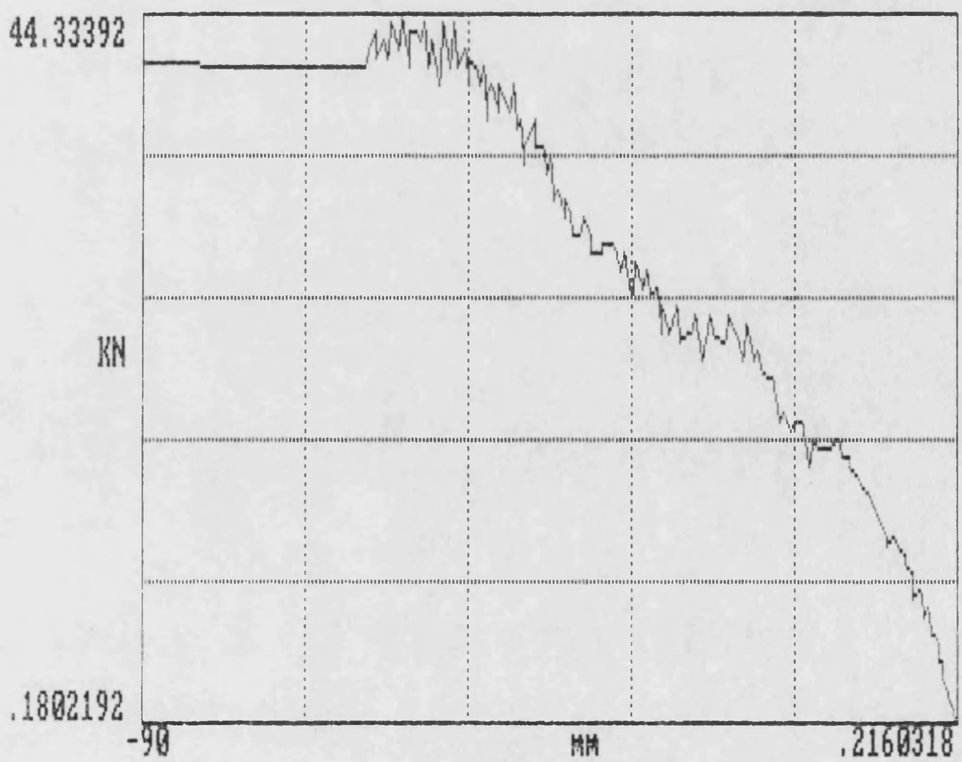
Original sample height = 335mm,

Cross - sectional area at 10% strain = 0.0563 m^2

LOAD18 v Time



LOAD18 v disp17



Number of Readings 260 No. Columns 4
Date Task Started 01/01/83 Time Task Started 00-22-42

	Time Secs 1	displ7 mm 2	LOAD18 KN 3	LOAD NON 4	
0	0.0	0.216	0.225	3	
1	2.0	0.216	0.180	2	
2	4.0	0.216	0.180	3	
3	6.0	0.216	0.180	2	
4	8.0	0.216	0.225	2	
5	10.0	0.216	0.180	2	
6	12.0	0.216	0.180	3	
7	14.0	0.216	0.180	2	
8	16.0	0.216	0.180	3	
9	18.0	0.216	0.180	3	
10	20.0	0.144	0.451	7	
11	22.0	-1.296	2.884	47	
12	24.0	-1.584	3.785	61	
13	26.0	-1.800	4.010	64	
14	28.0	-1.944	4.956	82	
15	30.0	-2.448	5.947	98	
16	32.0	-2.592	5.722	94	
17	34.0	-3.096	7.209	120	
18	36.0	-3.529	7.074	116	
19	38.0	-3.961	8.290	137	
20	40.0	-4.537	8.065	132	
21	42.0	-4.897	9.462	157	
22	44.0	-5.329	10.002	166	
23	46.0	-5.545	10.588	177	
24	48.0	-6.337	10.993	181	
25	50.0	-6.553	11.714	197	
26	52.0	-7.561	11.038	181	
27	54.0	-7.705	12.030	203	
28	56.0	-8.497	12.660	209	
29	58.0	-8.569	12.841	214	
30	60.0	-9.505	14.282	237	
31	62.0	-9.577	14.463	241	
32	64.0	-10.514	15.229	253	
33	66.0	-10.730	15.724	263	
34	68.0	-11.594	15.949	264	
35	70.0	-11.738	16.715	280	
36	72.0	-12.674	16.760	277	
37	74.0	-12.890	17.661	295	
38	76.0	-13.898	17.031	281	
39	78.0	-14.186	17.301	288	
40	80.0	-14.978	17.121	282	
41	82.0	-15.626	17.932	298	
42	84.0	-16.274	16.220	268	
43	86.0	-17.067	18.878	314	
44	88.0	-17.355	18.923	316	
45	90.0	-18.291	18.608	307	
46	92.0	-19.155	19.509	320	
47	94.0	-19.515	18.788	310	
48	96.0	-20.379	21.446	355	
49	98.0	-20.595	21.716	360	
50	100.0	-21.387	22.167	364	
51	102.0	-21.891	23.474	388	
52	104.0	-22.395	22.798	376	
53	106.0	-23.187	24.870	411	
54	108.0	-23.547	23.068	380	
55	110.0	-24.556	24.285	398	
56	112.0	-25.132	25.636	423	
57	114.0	-25.780	23.969	394	
58	116.0	-26.860	24.600	403	
59	118.0	-27.220	25.681	423	
60	120.0	-28.228	22.798	375	
61	122.0	-29.020	25.771	426	
62	124.0	-29.452	24.375	402	
63	126.0	-30.460	24.059	393	
64	128.0	-30.893	25.952	428	
65	130.0	-31.613	24.600	400	
66	132.0	-32.405	26.177	430	
67	134.0	-32.693	25.186	412	
68	136.0	-32.765	24.555	402	
69	138.0	-33.125	27.168	448	10%
70	140.0	-33.629	26.627	435	
71	142.0	-34.205	28.294	463	
72	144.0	-34.637	27.213	444	
73	146.0	-35.501	28.610	467	
74	148.0	-35.933	26.627	434	
75	150.0	-36.797	29.331	480	
76	152.0	-36.941	28.385	464	
77	154.0	-37.806	30.142	490	
78	156.0	-37.950	29.826	487	
79	158.0	-39.030	30.097	489	
80	160.0	-39.246	29.241	479	
81	162.0	-40.254	29.286	475	
82	164.0	-40.470	30.457	498	
83	166.0	-41.118	31.628	514	
84	168.0	-41.622	30.682	501	
85	170.0	-42.414	30.637	497	
86	172.0	-42.702	31.989	523	
87	174.0	-43.350	32.710	531	
88	176.0	-43.422	31.583	513	
89	178.0	-44.215	33.025	537	
90	180.0	-44.503	32.755	531	
91	182.0	-44.863	35.323	575	
92	184.0	-45.439	34.647	560	
93	186.0	-45.727	36.314	[illegible]	
94	188.0	-46.375	36.224	[illegible]	
95	190.0	-46.[illegible]	37.48[illegible]	[illegible]	
96	192.0	-47.[illegible]	35.819	578	
97	194.0	-47.[illegible]	34.872	564	
98	196.0	-48.031	37.801	614	
99	198.0	-48.607	37.170	600	
100	200.0	-49.039	39.874	646	
101	202.0	-49.543	38.477	621	

Number of Readings 260 No. Columns 4
Date Task Started 01/01/83 Time Task Started 00-22-42

Number of Readings 260 No. Columns 4
Date Task Started 01/01/83 Time Task Started 00-22-42

	Time Secs 1	displ7 mm 2	LOAD18 KN 3	LOAD NON 4
102	204.0	-49.831	39.017	633
103	206.0	-50.551	40.054	646
104	208.0	-50.695	38.522	621
105	210.0	-51.344	40.054	648
106	212.0	-51.776	39.243	632
107	214.0	-51.848	38.297	617
108	216.0	-51.920	37.846	611
109	218.0	-52.424	41.180	666
110	220.0	-52.784	40.189	648
111	222.0	-52.928	41.225	668
112	224.0	-53.792	41.360	666
113	226.0	-53.936	39.964	645
114	228.0	-54.512	42.352	684
115	230.0	-54.944	41.180	663
116	232.0	-55.520	43.748	706
117	234.0	-56.096	41.225	663
118	236.0	-56.600	43.523	702
119	238.0	-57.392	39.964	643
120	240.0	-57.897	42.712	691
121	242.0	-58.401	41.225	663
122	244.0	-58.833	43.928	709
123	246.0	-59.337	42.442	681
124	248.0	-59.553	43.433	701
125	250.0	-60.417	43.117	691
126	252.0	-60.633	41.225	663
127	254.0	-61.281	44.244	712
128	256.0	-61.641	42.261	679
129	258.0	-61.785	42.216	680
130	260.0	-62.577	44.019	709
131	262.0	-62.937	41.315	664
132	264.0	-63.513	42.442	682
133	266.0	-64.017	41.631	668
134	268.0	-64.233	43.072	696
135	270.0	-65.098	42.352	679
136	272.0	-65.242	41.000	658
137	274.0	-589.911	44.199	711
138	276.0	-589.911	41.586	666
139	278.0	-589.911	44.064	709
140	280.0	-589.911	42.892	687
141	282.0	-589.911	44.334	715
142	284.0	-589.911	43.253	690
143	286.0	-589.911	41.631	668
144	288.0	-589.911	43.928	708
145	290.0	-589.911	43.208	692
146	292.0	-589.911	42.306	677
147	294.0	-589.911	41.766	670
148	296.0	-589.911	41.450	664
149	298.0	-589.911	41.180	661
150	300.0	-589.911	41.000	658
151	302.0	-589.911	40.820	655
152	304.0	-589.911	40.730	653

peak

TRANSDUCER READINGS OUT OF RANGE.

Number of Readings 260 No. Columns 4
Date Task Started 01/01/83 Time Task Started 00-22-42

	Time Secs 1	displ7 mm 2	LOAD18 KN 3	LOAD NON 4
153	306.0	-589.911	40.639	652
154	308.0	-589.911	40.504	650
155	310.0	-589.911	40.414	649
156	312.0	-589.911	40.324	647
157	314.0	-589.911	40.234	646
158	316.0	-589.911	40.144	645
159	318.0	-589.911	40.099	644
160	320.0	-589.911	40.009	642
161	322.0	-589.911	39.964	640
162	324.0	-589.911	39.874	641
163	326.0	-589.911	39.828	639
164	328.0	-589.911	39.783	639
165	330.0	-589.911	39.738	638
166	332.0	-589.911	39.693	638
167	334.0	-589.911	39.648	636
168	336.0	-589.911	39.603	637
169	338.0	-589.911	39.558	635
170	340.0	-589.911	39.513	634
171	342.0	-589.911	39.513	634
172	344.0	-589.911	39.468	633
173	346.0	-589.911	39.378	632
174	348.0	-589.911	39.333	632
175	350.0	-589.911	39.333	632
176	352.0	-589.911	39.288	632
177	354.0	-589.911	39.288	630
178	356.0	-589.911	39.243	630
179	358.0	-589.911	39.198	630
180	360.0	-589.911	39.198	630
181	362.0	-589.911	39.153	629
182	364.0	-589.911	39.153	628
183	366.0	-589.911	39.108	629
184	368.0	-589.911	39.108	628
185	370.0	-589.911	39.063	627
186	372.0	-589.911	39.017	627
187	374.0	-589.911	39.017	626
188	376.0	-589.911	38.972	625
189	378.0	-589.911	38.927	626
190	380.0	-589.911	38.927	626
191	382.0	-589.911	38.927	625
192	384.0	-589.911	38.882	624
193	386.0	-589.911	38.882	623
194	388.0	-589.911	38.882	624
195	390.0	-589.911	38.837	623
196	392.0	-589.911	38.837	624
197	394.0	-589.911	38.792	623
198	396.0	-589.911	38.792	623
199	398.0	-589.911	38.792	623
200	400.0	-589.911	38.747	622
201	402.0	-589.911	38.747	623
202	404.0	-589.911	38.747	622
203	406.0	-589.911	38.702	622

Number of Readings 260 No. Columns 4
Date Task Started 01/01/83 Time Task Started 00-22-42

	Time Secs 1	disp17 mm 2	LOAD18 KN 3	LOAD NON 4
204	408.0	-589.911	38.702	622
205	410.0	-589.911	38.702	621
206	412.0	-589.911	38.657	621
207	414.0	-589.911	38.657	621
208	416.0	-589.911	38.657	621
209	418.0	-589.911	38.612	621
210	420.0	-589.911	38.612	620
211	422.0	-589.911	38.612	620
212	424.0	-589.911	38.612	620
213	426.0	-589.911	38.612	620
214	428.0	-589.911	38.567	620
215	430.0	-589.911	38.567	620
216	432.0	-589.911	38.567	619
217	434.0	-589.911	38.567	619
218	436.0	-589.911	38.522	619
219	438.0	-589.911	38.522	619
220	440.0	-589.911	38.522	619
221	442.0	-589.911	38.522	619
222	444.0	-589.911	38.522	618
223	446.0	-589.911	38.477	618
224	448.0	-589.911	38.477	619
225	450.0	-589.911	38.477	618
226	452.0	-589.911	38.477	619
227	454.0	-589.911	38.477	618
228	456.0	-589.911	38.477	618
229	458.0	-589.911	38.477	617
230	460.0	-589.911	38.477	617
231	462.0	-589.911	38.432	618
232	464.0	-589.911	38.432	617
233	466.0	-589.911	38.432	618
234	468.0	-589.911	38.432	617
235	470.0	-589.911	38.432	617
236	472.0	-589.911	38.387	616
237	474.0	-589.911	38.387	617
238	476.0	-589.911	38.387	618
239	478.0	-589.911	38.342	616
240	480.0	-589.911	38.342	617
241	482.0	-589.911	38.342	616
242	484.0	-589.911	38.297	616
243	486.0	-589.911	38.342	616
244	488.0	-589.911	38.297	616
245	490.0	-589.911	38.297	617
246	492.0	-589.911	38.297	616
247	494.0	-589.911	38.297	614
248	496.0	-589.911	38.252	615
249	498.0	-589.911	38.252	615
250	500.0	-589.911	38.252	616
251	502.0	-589.911	38.252	614
252	504.0	-589.911	38.252	615
253	506.0	-589.911	38.252	614
254	508.0	-589.911	38.252	614

Number of Readings 260 No. Columns 4
Date Task Started 01/01/83 Time Task Started 00-22-42

	Time Secs 1	disp17 mm 2	LOAD18 KN 3	LOAD NON 4
255	510.0	-589.911	38.206	614
256	512.0	-589.911	38.206	615
257	514.0	-589.911	38.206	614
258	516.0	-589.911	38.206	614
259	518.0	-589.911	38.206	614
260	520.0	-589.911	38.206	613

CALCULATION SHEET FOR TEST .... Triax 14

Peak axial load difference [kN] = 61.45
Axial compression [mm] = 62.30
} combination giving peak stress

Cross - sectional area [m^2] = 0.0623

Stress difference, $\sigma_1 - \sigma_3$ [kN/m^2] = 985

Cell pressure, σ_3 [kN/m^2] = 200

Angle of friction, ϕ = **45.38°**

Axial load difference at 10% axial strain [kN] = 39.33

Stress difference, $\sigma_1 - \sigma_3$ [kN/m^2] = 699

Cell pressure, σ_3 [kN/m^2] = 200

Angle of friction, ϕ = **39.50°**

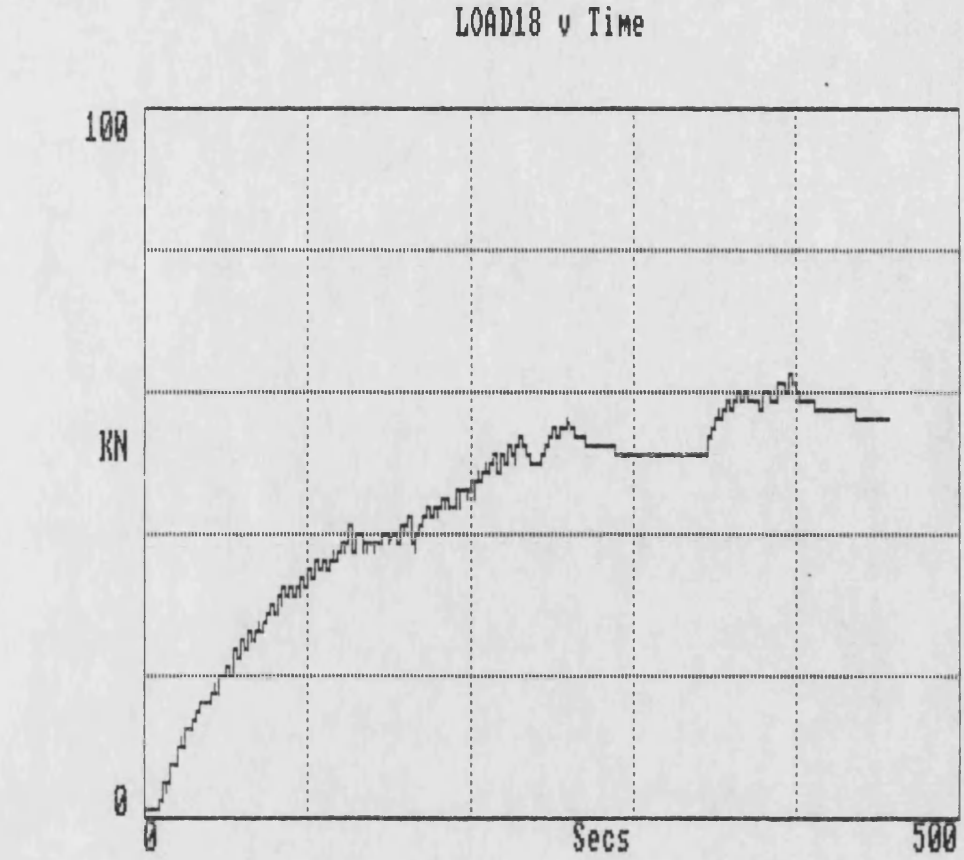
$$\text{Cross - sectional area} = \frac{\text{Sample volume}}{\text{Orig. height - axial comp.}}$$

$$\text{Angle of friction determined from; } \sin\phi = \frac{\sigma_1 - \sigma_3}{\sigma_1 + \sigma_3}$$

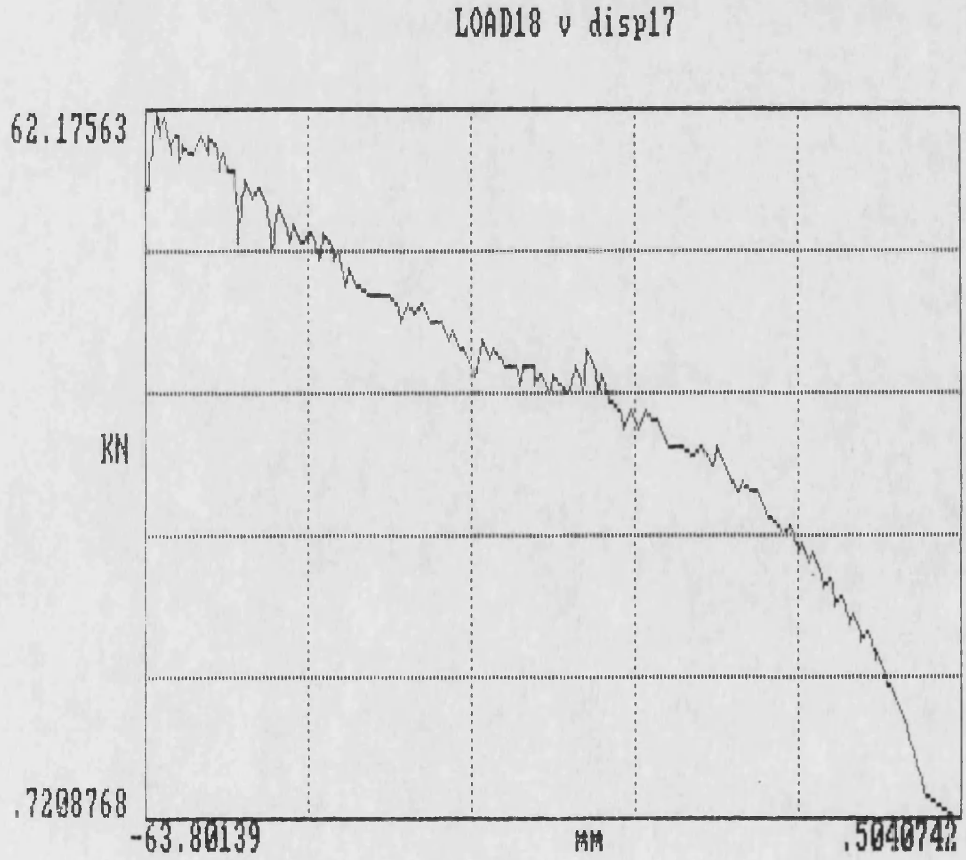
Sample volume = 0.017 m^3,

Original sample height = 335mm,

Cross - sectional area at 10% strain = 0.0563 m^2



LOAD18 v Time
100
KN
0
0
Secs
500



LOAD18 v disp17
62.17563
KN
.7208768
-63.80139
mm
.5040742

Number of Readings 317 No. Columns 4
Date Task Started 01/01/83 Time Task Started 00-31-19

	Time Secs 1	disp17 mm 2	LOAD18 KN 3	LOAD NON 4
0	0.0	0.504	0.721	11
1	2.0	0.504	0.721	10
2	4.0	0.504	0.721	11
3	6.0	0.504	0.721	10
4	8.0	0.504	0.721	11
5	10.0	0.504	0.721	10
6	12.0	0.504	0.721	10
7	14.0	0.504	0.721	11
8	16.0	0.504	0.721	10
9	18.0	0.072	1.081	18
10	20.0	-2.304	3.064	52
11	22.0	-2.736	4.505	74
12	24.0	-2.880	5.362	90
13	26.0	-3.312	7.164	121
14	28.0	-3.529	7.344	122
15	30.0	-3.817	9.146	152
16	32.0	-4.321	10.678	179
17	34.0	-4.465	10.678	179
18	36.0	-4.969	12.480	210
19	38.0	-5.329	12.165	203
20	40.0	-5.617	14.147	239
21	42.0	-6.193	15.093	252
22	44.0	-6.337	14.868	248
23	46.0	-6.697	16.580	279
24	48.0	-7.273	16.265	271
25	50.0	-7.489	16.851	283
26	52.0	-7.993	18.112	303
27	54.0	-8.281	17.842	297
28	56.0	-8.785	20.139	337
29	58.0	-9.289	19.419	323
30	60.0	-9.721	21.176	353
31	62.0	-10.442	21.041	350
32	64.0	-10.586	22.077	369
33	66.0	-11.234	23.744	395
34	68.0	-11.450	22.843	380
35	70.0	-11.954	24.780	411
36	72.0	-12.458	24.014	397
37	74.0	-12.818	25.997	432
38	76.0	-13.538	25.501	421
39	78.0	-13.826	26.177	432
40	80.0	-14.546	27.168	449
41	82.0	-14.834	27.168	450
42	84.0	-15.626	28.880	476
43	86.0	-15.842	29.015	480
44	88.0	-16.634	30.052	495
45	90.0	-17.067	29.241	482
46	92.0	-17.787	30.682	504
47	94.0	-18.003	30.637	505
48	96.0	-18.723	32.710	537
49	98.0	-19.083	31.538	519
50	100.0	-19.947	33.115	545

Number of Readings 317 No. Columns 4
Date Task Started 01/01/83 Time Task Started 00-31-19

	Time Secs 1	disp17 mm 2	LOAD18 KN 3	LOAD NON 4
51	102.0	-20.451	32.079	529
52	104.0	-21.315	32.800	537
53	106.0	-21.531	33.296	548
54	108.0	-22.539	33.025	539
55	110.0	-22.755	33.836	557
56	112.0	-23.547	35.053	571
57	114.0	-23.764	35.368	580
58	116.0	-24.484	35.909	586
59	118.0	-24.844	34.422	563
60	120.0	-25.492	36.089	592
61	122.0	-25.996	34.872	569
62	124.0	-26.356	36.359	595
63	126.0	-27.004	36.810	600
64	128.0	-27.220	37.170	606
65	130.0	-27.724	38.792	633
66	132.0	-28.084	37.801	615
67	134.0	-28.372	39.648	647
68	136.0	-28.876	41.360	674
69	138.0	-29.380	37.756	614
70	140.0	-29.524	39.423	643
71	142.0	-30.028	39.874	648
72	144.0	-30.605	37.711	614
73	146.0	-30.965	37.981	618
74	148.0	-31.541	38.882	634
75	150.0	-31.829	37.846	616
76	152.0	-32.405	39.288	640
77	154.0	-32.981	38.567	626
78	156.0	-33.197	39.648	647
79	158.0	-33.845	40.054	651 10%
80	160.0	-34.277	38.297	623
81	162.0	-34.637	40.234	655
82	164.0	-35.357	39.964	649
83	166.0	-35.717	40.549	662
84	168.0	-36.221	41.721	679
85	170.0	-36.581	40.639	661
86	172.0	-37.085	42.442	690
87	174.0	-37.806	38.747	626
88	176.0	-38.094	40.009	654
89	178.0	-38.742	41.676	678
90	180.0	-38.958	41.090	669
91	182.0	-39.534	43.027	700
92	184.0	-39.966	42.306	685
93	186.0	-40.470	43.568	707
94	188.0	-40.974	43.478	704
95	190.0	-41.262	44.109	716
96	192.0	-41.982	45.325	735
97	194.0	-42.342	44.424	722
98	196.0	-43.134	44.920	727
99	198.0	-43.494	43.568	704
100	200.0	-43.782	45.190	733
101	202.0	-44.431	45.866	741

Number of Readings 317 No. Columns 4
Date Task Started 01/01/83 Time Task Started 00-31-19

Number of Readings 317 No. Columns 4
Date Task Started 01/01/83 Time Task Started 00-31-19

	Time Secs 1	disp17 mm 2	LOAD18 KN 3	LOAD NON 4
102	204.0	-44.935	45.821	743
103	206.0	-45.583	46.406	750
104	208.0	-46.015	46.091	747
105	210.0	-46.735	46.902	758
106	212.0	-47.023	46.542	754
107	214.0	-47.599	48.434	783
108	216.0	-47.959	47.037	759
109	218.0	-48.463	49.786	806
110	220.0	-48.967	48.975	790
111	222.0	-49.183	50.506	815
112	224.0	-49.759	51.408	830
113	226.0	-50.119	49.155	792
114	228.0	-50.695	51.498	832
115	230.0	-51.200	50.912	820
116	232.0	-51.416	50.867	823
117	234.0	-52.064	52.173	841
118	236.0	-52.424	50.551	815
119	238.0	-52.712	52.399	846
120	240.0	-53.144	53.525	863
121	242.0	-53.432	52.173	839
122	244.0	-53.504	51.362	828
123	246.0	-53.576	50.732	818
124	248.0	-53.648	50.281	812
125	250.0	-53.720	49.876	805
126	252.0	-53.720	49.560	800
127	254.0	-53.792	51.498	833
128	256.0	-54.080	53.075	857
129	258.0	-54.296	53.345	859
130	260.0	-54.656	55.282	890
131	262.0	-55.232	54.111	870
132	264.0	-55.448	54.516	880
133	266.0	-55.592	55.192	891
134	268.0	-55.808	56.003	904
135	270.0	-56.024	55.462	893
136	272.0	-56.096	54.787	882
137	274.0	-56.168	54.111	872
138	276.0	-56.240	53.660	865
139	278.0	-56.240	53.345	859
140	280.0	-56.312	53.075	856
141	282.0	-56.312	52.894	852
142	284.0	-56.312	52.624	848
143	286.0	-56.384	52.444	845
144	288.0	-56.384	52.309	844
145	290.0	-56.384	52.219	842
146	292.0	-56.384	52.083	840
147	294.0	-56.384	51.993	839
148	296.0	-56.384	51.948	838
149	298.0	-56.384	51.858	836
150	300.0	-56.384	51.768	836
151	302.0	-56.384	51.768	834
152	304.0	-56.456	51.678	834
153	306.0	-56.456	51.633	833
154	308.0	-56.456	51.588	833
155	310.0	-56.456	51.543	831
156	312.0	-56.456	51.498	830
157	314.0	-56.456	51.408	829
158	316.0	-56.456	51.362	829
159	318.0	-56.456	51.362	829
160	320.0	-56.456	51.317	827
161	322.0	-56.456	51.272	826
162	324.0	-56.456	51.227	827
163	326.0	-56.456	51.182	826
164	328.0	-56.456	51.137	825
165	330.0	-56.528	51.092	825
166	332.0	-56.528	51.047	824
167	334.0	-56.528	51.047	824
168	336.0	-56.528	51.002	823
169	338.0	-56.528	51.002	823
170	340.0	-56.528	50.957	822
171	342.0	-56.528	50.912	822
172	344.0	-56.528	50.867	821
173	346.0	-56.528	50.867	821
174	348.0	-56.528	50.822	820
175	350.0	-56.528	50.822	820
176	352.0	-56.528	50.777	820
177	354.0	-56.528	50.777	820
178	356.0	-56.528	53.210	861
179	358.0	-56.672	55.462	895
180	360.0	-56.888	56.499	911
181	362.0	-57.104	56.499	909
182	364.0	-57.320	56.904	918
183	366.0	-57.680	57.986	934
184	368.0	-57.897	57.805	930
185	370.0	-57.969	56.994	917
186	372.0	-58.185	59.157	956
187	374.0	-58.689	59.833	964
188	376.0	-58.977	58.346	938
189	378.0	-59.481	60.013	965
190	380.0	-59.913	58.436	940
191	382.0	-60.417	58.706	946
192	384.0	-60.777	58.977	950
193	386.0	-60.993	58.256	936
194	388.0	-61.065	57.535	926
195	390.0	-61.281	60.148	[illegible]
196	392.0	-61.569	[illegible]	[illegible]
197	394.0	[illegible]	[illegible]	952
198	396.0	-61.857	58.481	941
199	398.0	-62.073	59.788	963
200	400.0	-62.361	61.139	984
201	402.0	-62.577	60.644	975
202	404.0	-62.649	59.833	962
203	406.0	-62.793	62.176	1001

peak

Number of Readings 317 No. Columns 4
Date Task Started 01/01/83 Time Task Started 00-31-19

	Time Secs 1	disp17 mm 2	LOAD18 KN 3	LOAD NON 4
204	408.0	-62.937	61.229	983
205	410.0	-63.081	60.193	967
206	412.0	-63.153	59.517	957
207	414.0	-63.225	59.022	949
208	416.0	-63.225	58.751	944
209	418.0	-63.297	58.481	941
210	420.0	-63.297	58.346	938
211	422.0	-63.297	58.031	933
212	424.0	-63.369	57.850	931
213	426.0	-63.369	57.715	928
214	428.0	-63.369	57.535	926
215	430.0	-63.369	57.445	924
216	432.0	-63.441	57.355	923
217	434.0	-63.441	57.310	922
218	436.0	-63.441	57.220	921
219	438.0	-63.441	57.129	920
220	440.0	-63.441	57.084	918
221	442.0	-63.441	56.994	918
222	444.0	-63.441	56.949	917
223	446.0	-63.441	56.904	916
224	448.0	-63.513	56.724	913
225	450.0	-63.513	56.634	912
226	452.0	-63.513	56.544	910
227	454.0	-63.513	56.454	908
228	456.0	-63.513	56.409	908
229	458.0	-63.513	56.319	907
230	460.0	-63.513	56.273	906
231	462.0	-63.513	56.183	905
232	464.0	-63.585	56.138	903
233	466.0	-63.585	56.093	902
234	468.0	-63.585	56.048	902
235	470.0	-63.585	56.003	901
236	472.0	-63.585	55.958	899
237	474.0	-63.585	55.913	900
238	476.0	-63.585	55.868	899
239	478.0	-63.585	55.823	898
240	480.0	-63.585	55.778	898
241	482.0	-63.585	55.733	898
242	484.0	-63.585	55.733	897
243	486.0	-63.585	55.688	896
244	488.0	-63.585	55.643	896
245	490.0	-63.657	55.598	896
246	492.0	-63.657	55.553	895
247	494.0	-63.585	55.553	895
248	496.0	-63.585	55.508	895
249	498.0	-63.657	55.462	893
250	500.0	-63.657	55.417	892
251	502.0	-63.657	55.417	892
252	504.0	-63.657	55.372	892
253	506.0	-63.657	55.372	892
254	508.0	-63.657	55.327	891

Number of Readings 317 No. Columns 4
Date Task Started 01/01/83 Time Task Started 00-31-19

	Time Secs 1	disp17 mm 2	LOAD18 KN 3	LOAD NON 4
255	510.0	-63.657	55.282	891
256	512.0	-63.657	55.282	891
257	514.0	-63.657	55.237	890
258	516.0	-63.657	55.237	888
259	518.0	-63.657	55.192	889
260	520.0	-63.657	55.147	888
261	522.0	-63.657	55.147	888
262	524.0	-63.657	55.102	888
263	526.0	-63.657	55.102	888
264	528.0	-63.657	55.057	887
265	530.0	-63.657	55.057	886
266	532.0	-63.729	55.012	887
267	534.0	-63.729	55.012	886
268	536.0	-63.657	54.967	885
269	538.0	-63.729	54.922	886
270	540.0	-63.657	54.922	885
271	542.0	-63.657	54.877	884
272	544.0	-63.729	54.877	885
273	546.0	-63.729	54.877	885
274	548.0	-63.729	54.832	883
275	550.0	-63.729	54.832	882
276	552.0	-63.729	54.787	881
277	554.0	-63.729	54.787	882
278	556.0	-63.729	54.742	882
279	558.0	-63.729	54.742	881
280	560.0	-63.729	54.742	882
281	562.0	-63.729	54.697	881
282	564.0	-63.729	54.697	881
283	566.0	-63.729	54.697	880
284	568.0	-63.729	54.651	880
285	570.0	-63.729	54.651	880
286	572.0	-63.729	54.606	880
287	574.0	-63.729	54.606	879
288	576.0	-63.729	54.561	879
289	578.0	-63.729	54.561	878
290	580.0	-63.729	54.561	879
291	582.0	-63.729	54.516	879
292	584.0	-63.729	54.516	879
293	586.0	-63.729	54.471	876
294	588.0	-63.729	54.471	877
295	590.0	-63.729	54.471	877
296	592.0	-63.729	54.471	876
297	594.0	-63.729	54.426	876
298	596.0	-63.729	54.426	875
299	598.0	-63.729	54.426	877
300	600.0	-63.729	54.381	875
301	602.0	-63.729	54.381	876
302	604.0	-63.729	54.381	875
303	606.0	-63.729	54.336	876
304	608.0	-63.729	54.336	874
305	610.0	-63.801	54.336	874

Number of Readings 317 No. Columns 4
Date Task Started 01/01/83 Time Task Started 00-31-19

	Time Secs 1	disp17 mm 2	LOAD18 KN 3	LOAD NON 4
306	612.0	-63.801	54.291	875
307	614.0	-63.801	54.291	875
308	616.0	-63.729	54.291	875
309	618.0	-63.729	54.246	874
310	620.0	-63.729	54.246	874
311	622.0	-63.801	54.246	873
312	624.0	-63.801	54.201	873
313	626.0	-63.801	54.201	874
314	628.0	-63.801	54.201	873
315	630.0	-63.801	54.156	873
316	632.0	-63.801	54.156	873
317	634.0	-63.801	54.156	873

Data from dynamic verification tests. 254mm samples only.

Data output from ADU, utilising DIALOG software and screen dumps.

Includes;

1. Print out of logged data. Strain rings [mm or ADU units], internal LVDT [ADU units], external actuator load cell [kN], and actuator LVDT [mm].

2. Load vs stroke plot from external sensors. XY plot from Dialog software (Screen dump).

3. Selected strain ring vs stroke plots.

4. Selected strain ring vs load plots.

mber of Readings 200 No. Columns 8
te Task Started 01/01/83 Time Task Started 00-11-00

	Time	STRING5/16	STRING5/12	STRING3/12	STRING3/16	LVDT	LOAD	STROKE
	Secs	NON	NON	NON	NON	NON	KN	MM
	1	2	3	4	5	6	7	8
	0.0	-175	164	162.0	-175.0	-1423	-1.8555	125.0742
	0.0	-174	162	158.0	-176.0	-1429	-9.1552	123.5164
	0.0	-172	168	145.0	-179.0	-1427	-12.3535	123.3680
	0.0	-165	163	105.0	-182.0	-1425	-20.7519	122.9229
	0.0	-168	173	153.0	-180.0	-1422	-11.3769	123.2196
	0.0	-174	157	155.0	-172.0	-1422	-1.2451	124.1098
	1.0	-174	175	130.0	-173.0	-1430	-1.1475	125.0000
	1.0	-174	153	170.0	-175.0	-1425	-1.1475	125.4451
	1.0	-175	173	151.0	-174.0	-1422	-1.8311	125.0742
	1.0	-176	160	154.0	-174.0	-1424	-1.9775	124.2582
0	2.0	-172	164	140.0	-178.0	-1426	-12.1338	123.2938
1	2.0	-166	161	166.0	-183.0	-1422	-20.6542	122.9229
2	2.0	-168	159	137.0	-180.0	-1422	-11.1816	123.2196
3	2.0	-173	174	162.0	-172.0	-1427	-1.2451	124.1098
4	3.0	-174	161	142.0	-174.0	-1426	-1.1719	125.0000
5	3.0	-176	173	161.0	-175.0	-1422	-1.1475	125.4451
6	3.0	-175	162	141.0	-174.0	-1424	-1.8311	125.0742
7	3.0	-176	167	159.0	-175.0	-1427	-1.9775	124.2582
8	4.0	-173	160	150.0	-179.0	-1423	-11.9873	123.3680
9	4.0	-166	168	139.0	-182.0	-1422	-20.5322	122.9229
0	4.0	-168	160	160.0	-180.0	-1426	-11.0351	123.2196
1	4.0	-174	165	131.0	-174.0	-1430	-1.2695	124.1098
2	5.0	-174	160	159.0	-176.0	-1429	-1.1475	125.0000
3	5.0	-175	169	138.0	-175.0	-1423	-1.1475	125.4451
4	5.0	-176	162	162.0	-175.0	-1423	-1.8311	125.0742
5	5.0	-176	170	148.0	-175.0	-1427	-1.9775	124.2582
6	6.0	-173	164	159.0	-179.0	-1423	-11.8408	123.3680
7	6.0	-166	155	127.0	-183.0	-1425	-20.3613	122.9229
8	6.0	-169	165	134.0	-181.0	-1429	-10.4980	123.2938
9	6.0	-174	164	127.0	-179.0	-1422	-1.2695	124.1098
0	7.0	-176	172	133.0	-176.0	-1423	-1.1475	125.0742
1	7.0	-176	166	164.0	-176.0	-1423	-1.1475	125.4451
2	7.0	-176	171	142.0	-174.0	-1426	-1.8555	125.0742
3	7.0	-176	164	150.0	-175.0	-1428	-1.9531	124.2582
4	8.0	-174	163	153.0	-178.0	-1429	-11.8652	123.3680
5	8.0	-167	163	132.0	-182.0	-1425	-20.2636	122.9229
6	8.0	-170	163	146.0	-181.0	-1426	-10.5469	123.2938
7	8.0	-176	163	141.0	-178.0	-1426	-1.2451	124.1840
8	9.0	-177	169	147.0	-177.0	-1422	-1.1475	125.0742
9	9.0	-176	164	127.0	-177.0	-1428	-1.1475	125.4451
0	9.0	-177	168	145.0	-175.0	-1423	-1.8311	125.1484
1	9.0	-177	163	144.0	-175.0	-1422	-1.9775	124.1840
2	10.0	-174	163	148.0	-179.0	-1423	-11.8652	123.3680
3	10.0	-169	170	158.0	-182.0	-1423	-20.1171	122.9229
4	10.0	-170	162	153.0	-180.0	-1422	-10.5469	123.2938
5	10.0	-178	161	147.0	-179.0	-1423	-1.2451	124.1098
6	11.0	-177	163	120.0	-177.0	-1429	-1.1475	125.0742
7	11.0	-176	163	132.0	-176.0	-1423	-1.1475	125.4451
8	11.0	-177	171	139.0	-175.0	-1425	-1.8311	125.0742
9	11.0	-177	164	146.0	-175.0	-1424	-1.9775	124.2582
0	12.0	-173	163	153.0	-180.0	-1423	-11.5967	123.2938

lumber of Readings 200 No. Columns 8
ate Task Started 01/01/83 Time Task Started 00-11-00

	Time	STRING5/16	STRING5/12	STRING3/12	STRING3/16	LVDT	LOAD	STROKE
	Secs	NON	NON	NON	NON	NON	KN	MM
	1	2	3	4	5	6	7	8
51	12.0	-169	169	134.0	-184.0	-1423	-19.9951	122.9229
52	12.0	-170	165	155.0	-182.0	-1426	-10.4980	123.2938
53	12.0	-178	168	142.0	-179.0	-1422	-1.2451	124.1098
54	13.0	-178	176	163.0	-177.0	-1425	-1.1475	125.0742
55	13.0	-177	164	139.0	-177.0	-1423	-1.1475	125.4451
56	13.0	-178	166	140.0	-176.0	-1426	-1.8311	125.0742
57	13.0	-177	173	145.0	-176.0	-1428	-2.0019	124.1840
58	14.0	-174	172	138.0	-180.0	-1425	-11.5722	123.3680
59	14.0	-170	160	152.0	-185.0	-1423	-19.8242	122.9229
60	14.0	-171	162	145.0	-182.0	-1430	-10.3759	123.2196
61	14.0	-180	170	164.0	-177.0	-1426	-1.2451	124.1840
62	15.0	-178	170	149.0	-178.0	-1429	-1.1475	125.0742
63	15.0	-177	159	169.0	-178.0	-1423	-1.1475	125.4451
64	15.0	-177	167	151.0	-177.0	-1426	-1.8311	125.0742
65	15.0	-177	167	133.0	-177.0	-1423	-1.9775	124.2582
66	16.0	-173	171	143.0	-181.0	-1423	-11.7431	123.2938
67	16.0	-169	171	150.0	-184.0	-1425	-19.7753	122.9229
68	16.0	-171	167	153.0	-183.0	-1423	-10.2783	123.2938
69	16.0	-180	169	140.0	-177.0	-1423	-1.2451	124.1098
70	17.0	-179	183	126.0	-176.0	-1424	-1.1475	125.0742
71	17.0	-176	160	145.0	-178.0	-1423	-1.1475	125.4451
72	17.0	-177	166	163.0	-178.0	-1427	-1.8311	125.1484
73	17.0	-178	167	147.0	-177.0	-1428	-1.9775	124.1840
74	18.0	-173	166	131.0	-181.0	-1429	-11.6211	123.3680
75	18.0	-169	171	150.0	-184.0	-1425	-19.7021	122.9229
76	18.0	-171	164	150.0	-183.0	-1424	-10.2051	123.2938
77	18.0	-181	175	165.0	-177.0	-1423	-1.2451	124.1098
78	19.0	-178	172	147.0	-178.0	-1427	-1.1475	125.0742
79	19.0	-177	174	141.0	-178.0	-1423	-1.1475	125.4451
80	19.0	-178	172	146.0	-178.0	-1426	-1.8311	125.0742
81	19.0	-178	168	156.0	-177.0	-1424	-1.9775	124.1840
82	20.0	-173	172	137.0	-180.0	-1423	-11.4013	123.2938
83	20.0	-171	164	154.0	-185.0	-1426	-19.6044	122.9229
84	20.0	-172	167	135.0	-182.0	-1425	-9.7656	123.2938
85	20.0	-180	167	127.0	-174.0	-1423	-1.2451	124.1840
86	21.0	-179	173	147.0	-178.0	-1429	-1.1475	125.0742
87	21.0	-177	164	151.0	-178.0	-1423	-1.1475	125.4451
88	21.0	-178	169	154.0	-178.0	-1427	-1.8311	125.0742
89	21.0	-178	166	158.0	-177.0	-1428	-1.9775	124.2582
90	22.0	-174	166	152.0	-180.0	-1428	-11.3281	123.2938
91	22.0	-169	161	163.0	-185.0	-1428	-19.5068	122.9229
92	22.0	-172	167	135.0	-182.0	-1427	-9.7900	123.2938
93	22.0	-179	178	154.0	-173.0	-1429	-1.2207	124.1840
94	23.0	-178	168	134.0	-177.0	-1423	-1.1475	125.0742
95	23.0	-178	164	150.0	-178.0	-1423	-1.1475	125.4451
96	23.0	-179	169	161.0	-177.0	-1423	-1.8311	125.1484
97	23.0	-179	171	148.0	-177.0	-1430	-1.9775	124.1840
98	24.0	-174	170	143.0	-181.0	-1423	-11.3769	123.3680
99	24.0	-169	172	132.0	-184.0	-1428	-19.4091	122.9229
100	24.0	-172	172	143.0	-183.0	-1425	-9.7412	123.2938
101	24.0	-179	183	150.0	-175.0	-1424	-1.2451	124.1840

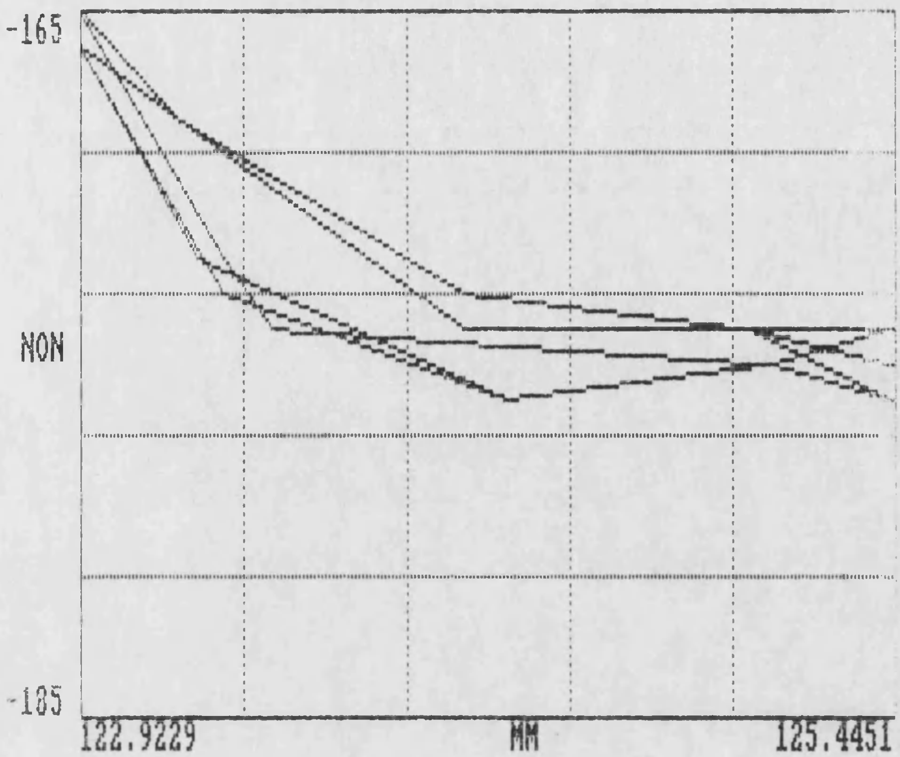
mber of Readings 200 No. Columns 8
te Task Started 01/01/83 Time Task Started 00-11-00

	Time Secs 1	STRING5/16 NON 2	STRING5/12 NON 3	STRING3/12 NON 4	STRING3/16 NON 5	LVDT NON 6	LOAD KN 7	STROKE MM 8
02	25.0	-178	167	125.0	-177.0	-1430	-1.1475	125.0742
03	25.0	-179	164	164.0	-180.0	-1423	-1.1230	125.4451
04	25.0	-179	173	146.0	-179.0	-1425	-1.8311	125.0742
05	25.0	-180	172	147.0	-178.0	-1422	-2.0019	124.1840
06	26.0	-175	169	153.0	-180.0	-1427	-11.1816	123.2938
07	26.0	-170	183	163.0	-185.0	-1425	-19.4091	122.9229
08	26.0	-173	173	142.0	-183.0	-1424	-9.4726	123.2938
09	26.0	-177	178	133.0	-177.0	-1423	-1.2451	124.1840
10	27.0	-179	179	137.0	-177.0	-1426	-1.1475	125.0742
11	27.0	-179	170	142.0	-178.0	-1423	-1.1475	125.4451
12	27.0	-179	172	151.0	-178.0	-1427	-1.8311	125.0742
13	27.0	-179	169	142.0	-177.0	-1424	-1.9775	124.1840
14	28.0	-175	166	145.0	-181.0	-1424	-11.3037	123.2938
15	28.0	-170	158	160.0	-185.0	-1428	-19.2382	122.9229
16	28.0	-173	168	151.0	-183.0	-1426	-9.7168	123.2938
17	28.0	-178	176	146.0	-175.0	-1424	-1.2207	124.1840
18	29.0	-180	167	162.0	-179.0	-1427	-1.1475	125.0742
19	29.0	-179	165	155.0	-179.0	-1425	-1.1475	125.4451
20	29.0	-180	178	150.0	-179.0	-1424	-1.8311	125.0742
21	29.0	-179	170	153.0	-178.0	-1424	-1.9775	124.2582
22	30.0	-176	170	152.0	-180.0	-1427	-10.9619	123.3680
23	30.0	-171	158	161.0	-185.0	-1423	-19.1650	122.9971
24	30.0	-174	172	148.0	-184.0	-1427	-9.5215	123.2938
25	30.0	-175	177	154.0	-180.0	-1425	-1.2207	124.1840
26	31.0	-179	184	154.0	-178.0	-1423	-1.1475	125.0742
27	31.0	-179	178	137.0	-179.0	-1429	-1.1475	125.4451
28	31.0	-180	167	162.0	-179.0	-1425	-1.8311	125.0742
29	31.0	-180	167	156.0	-178.0	-1425	-1.9775	124.1840
30	32.0	-177	174	148.0	-179.0	-1425	-11.0107	123.2938
31	32.0	-173	177	157.0	-185.0	-1429	-19.1162	122.9971
32	32.0	-174	170	139.0	-182.0	-1428	-9.2529	123.2938
33	32.0	-175	165	156.0	-181.0	-1423	-1.2451	124.1840
34	33.0	-178	164	168.0	-177.0	-1423	-1.1475	125.0742
35	33.0	-180	168	172.0	-179.0	-1430	-1.1230	125.4451
36	33.0	-180	174	149.0	-178.0	-1429	-1.8311	125.0742
37	33.0	-180	172	150.0	-177.0	-1423	-1.9531	124.1840
38	34.0	-177	175	144.0	-179.0	-1428	-11.1328	123.2938
39	34.0	-171	161	165.0	-185.0	-1423	-19.0185	122.9229
40	34.0	-174	170	145.0	-183.0	-1430	-9.4482	123.2938
41	34.0	-176	166	167.0	-178.0	-1423	-1.2451	124.1840
42	35.0	-179	166	167.0	-179.0	-1426	-1.1475	125.0742
43	35.0	-179	178	141.0	-179.0	-1425	-1.1475	125.4451
44	35.0	-180	170	142.0	-179.0	-1423	-1.8311	125.0742
45	35.0	-181	176	146.0	-178.0	-1428	-1.9775	124.1840
46	36.0	-176	171	151.0	-180.0	-1426	-10.8154	123.3680
47	36.0	-172	163	124.0	-185.0	-1424	-18.9697	122.9229
48	36.0	-174	173	147.0	-183.0	-1424	-9.2773	123.2938
49	36.0	-178	172	147.0	-184.0	-1426	-1.2451	124.1840
50	37.0	-179	166	141.0	-180.0	-1423	-1.1475	125.0742
51	37.0	-179	167	166.0	-179.0	-1426	-1.1475	125.4451
52	37.0	-180	168	158.0	-179.0	-1430	-1.8311	125.0742

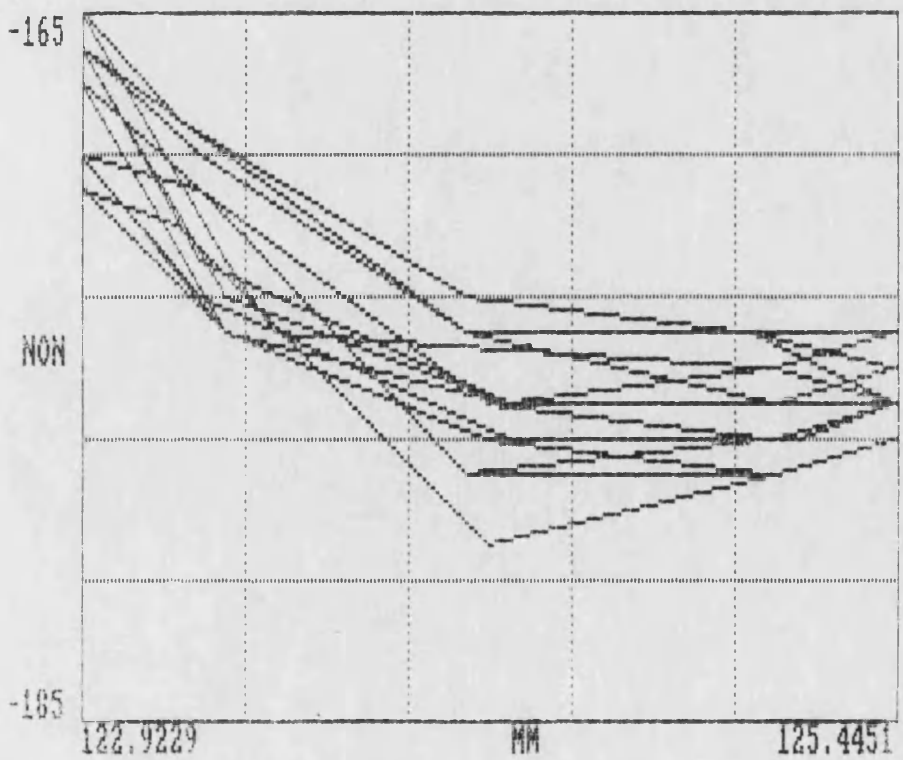
Number of Readings 200 No. Columns 8
Date Task Started 01/01/83 Time Task Started 00-11-00

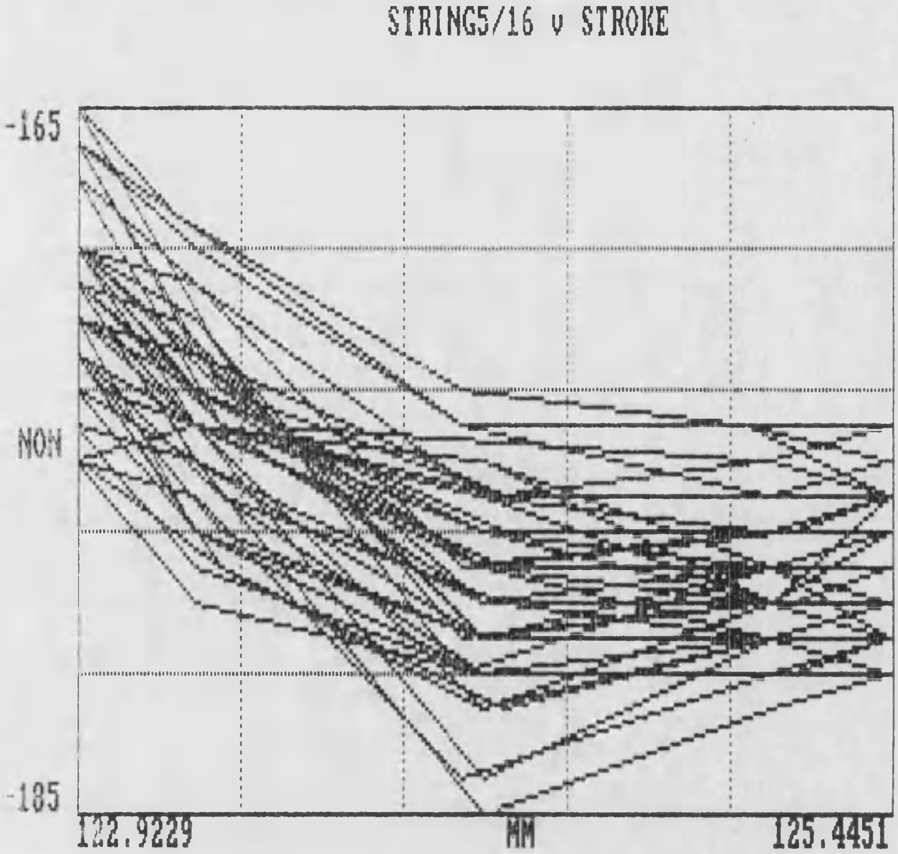
	Time Secs 1	STRING5/16 NON 2	STRING5/12 NON 3	STRING3/12 NON 4	STRING3/16 NON 5	LVDT NON 6	LOAD KN 7	STROKE MM 8
153	37.0	-180	176	147.0	-178.0	-1427	-1.9775	124.1840
154	38.0	-177	174	148.0	-180.0	-1430	-10.8642	123.3680
155	38.0	-172	163	145.0	-185.0	-1424	-18.8964	122.9229
156	38.0	-174	171	136.0	-183.0	-1423	-8.9355	123.2938
157	38.0	-178	181	161.0	-182.0	-1423	-1.2451	124.1840
158	39.0	-179	164	162.0	-180.0	-1428	-1.1475	125.0742
159	39.0	-180	165	166.0	-179.0	-1428	-1.1475	125.4451
160	39.0	-180	169	162.0	-179.0	-1423	-1.8311	125.0742
161	39.0	-181	178	147.0	-178.0	-1430	-1.9775	124.1840
162	40.0	-177	172	138.0	-180.0	-1427	-11.0107	123.2938
163	40.0	-173	159	172.0	-185.0	-1428	-18.8964	122.9229
164	40.0	-175	172	147.0	-183.0	-1425	-9.2041	123.2938
165	40.0	-179	170	145.0	-184.0	-1424	-1.2451	124.1840
166	41.0	-179	166	169.0	-181.0	-1423	-1.1475	125.0742
167	41.0	-180	168	160.0	-179.0	-1423	-1.1475	125.4451
168	41.0	-180	177	136.0	-179.0	-1424	-1.8555	125.0742
169	41.0	-182	175	150.0	-178.0	-1423	-1.9775	124.1840
170	42.0	-178	171	154.0	-180.0	-1428	-10.7177	123.3680
171	42.0	-175	180	166.0	-186.0	-1428	-18.8232	122.9229
172	42.0	-174	171	150.0	-184.0	-1429	-9.0820	123.2938
173	42.0	-182	164	131.0	-183.0	-1426	-1.2451	124.1840
174	43.0	-179	180	135.0	-179.0	-1429	-1.1475	125.0742
175	43.0	-180	173	146.0	-178.0	-1426	-1.1230	125.4451
176	43.0	-180	168	161.0	-179.0	-1429	-1.8311	125.0742
177	43.0	-182	174	163.0	-179.0	-1423	-1.9775	124.2582
178	44.0	-178	172	155.0	-180.0	-1428	-10.7422	123.3680
179	44.0	-172	166	121.0	-185.0	-1423	-18.7744	122.9229
180	44.0	-174	174	140.0	-183.0	-1423	-8.7402	123.2938
181	44.0	-184	171	152.0	-184.0	-1423	-1.2451	124.1840
182	45.0	-180	166	166.0	-179.0	-1428	-1.1475	125.0742
183	45.0	-181	168	167.0	-180.0	-1426	-1.1475	125.4451
184	45.0	-180	178	147.0	-178.0	-1428	-1.8311	125.0742
185	45.0	-181	177	152.0	-178.0	-1423	-1.9775	124.1840
186	46.0	-178	176	149.0	-180.0	-1429	-10.8886	123.2938
187	46.0	-174	161	138.0	-186.0	-1423	-18.7255	122.9229
188	46.0	-175	171	150.0	-182.0	-1424	-8.8867	123.2938
189	46.0	-185	175	144.0	-183.0	-1429	-1.2207	124.1840
190	47.0	-182	179	143.0	-179.0	-1430	-1.1475	125.0742
191	47.0	-181	169	133.0	-178.0	-1425	-1.1475	125.4451
192	47.0	-181	170	142.0	-178.0	-1423	-1.8311	125.0742
193	47.0	-181	170	160.0	-177.0	-1427	-1.9775	124.1840
194	48.0	-179	171	156.0	-180.0	-1424	-10.6445	123.2938
195	48.0	-175	174	169.0	-185.0	-1426	-18.6523	122.9229
196	48.0	-176	170	158.0	-182.0	-1425	-8.8135	123.2938
197	48.0	-184	178	154.0	-178.0	-1426	-1.2451	124.1098
198	49.0	-181	167	145.0	-180.0	-1423	-1.1475	125.0742
199	49.0	-180	168	167.0	-178.0	-1427	-1.1475	125.4451
200	49.0	-181	175	150.0	-177.0	-1425	-1.8311	125.1484

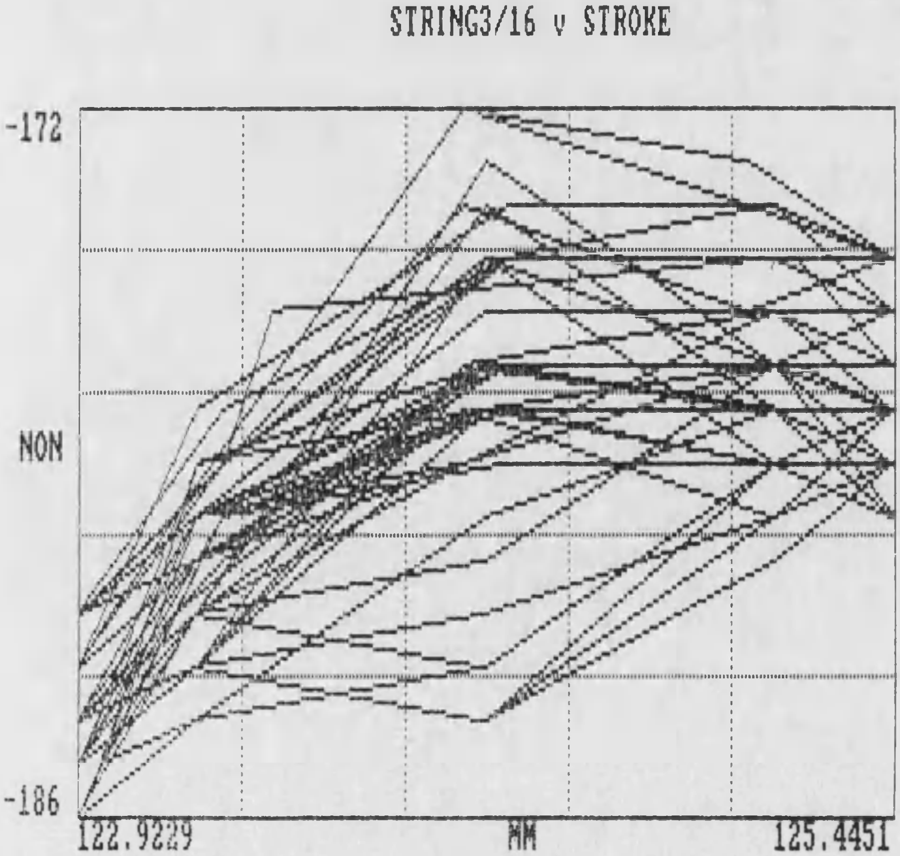
STRING5/16 v STROKE

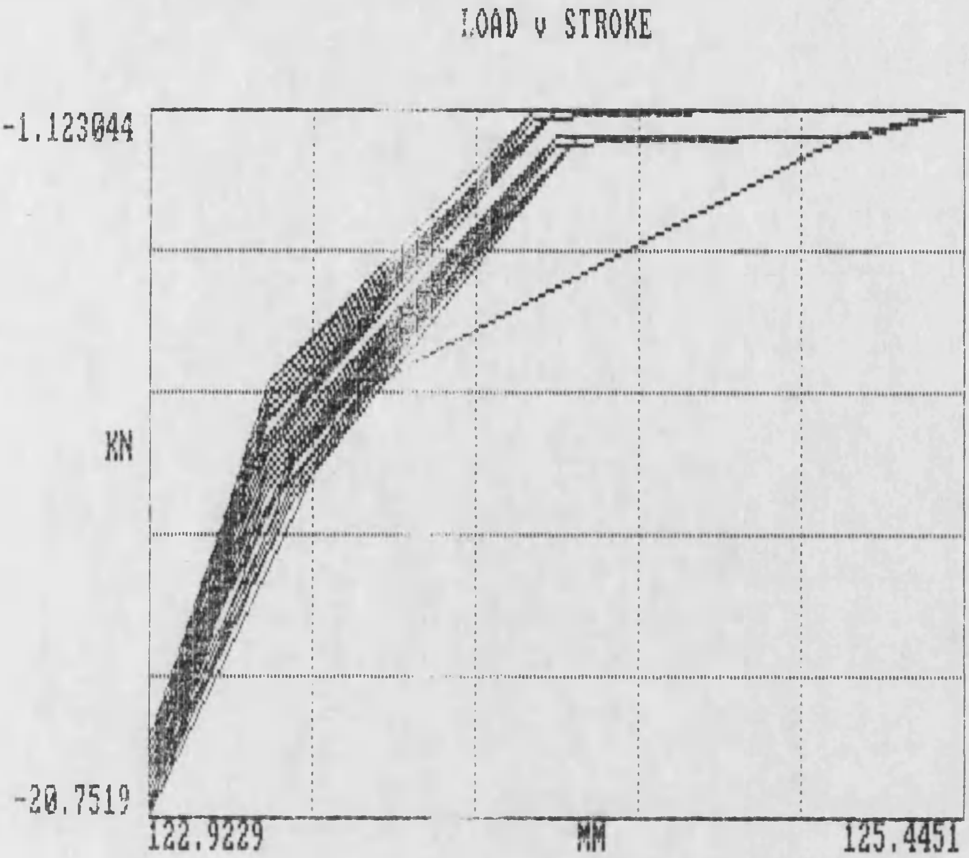


STRING5/16 v STROKE




STRING5/16 v STROKE
-165
NON
-185
122.9229
MM
125.4451


STRING3/16 v STROKE
-172
NON
-186
122.9229
MM
125.4451


LOAD v STROKE
-1.123044
KN
-20.7519
122.9229
MM
125.4451

mber of Readings 200 No. Columns 8
te Task Started 01/01/83 Time Task Started 00-23-19

	Time Secs 1	STRING5/16 NON 2	STRING5/12 NON 3	STRING3/12 NON 4	STRING3/16 NON 5	LVDT NON 6	LOAD KN 7	STROKE MM 8
	0.0	-199	195	157.0	-24.0	-1431	-16.3818	122.2552
	0.0	-198	198	[illegible]	18.0	-1428	-1.1230	125.2226
	0.0	-197	[illegible]	[illegible]	17.0	-1426	[illegible]	[illegible]
	0.0	-196	[illegible]	[illegible]	[illegible]	[illegible]	-1.7090	125.2226
	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	-1430	1.9287	124.2582
	[illegible]			[illegible]	-17.0	-1430	-3.5644	122.9971
	[illegible]	-190	199	162.0	-23.0	-1426	-20.4589	122.1810
	1.0	-190	198	162.0	-24.0	-1425	-16.2109	122.2552
	1.0	-198	202	165.0	-19.0	-1427	-1.2939	123.2196
	1.0	-197	201	166.0	-17.0	-1430	-1.1719	124.4808
0	2.0	-198	201	169.0	-18.0	-1430	-1.1230	125.2968
1	2.0	-198	200	169.0	-19.0	-1427	-1.7090	125.2226
2	2.0	-199	200	169.0	-18.0	-1426	-1.9531	124.2582
3	2.0	-196	204	163.0	-16.0	-1427	-3.4668	122.9971
4	3.0	-191	197	162.0	-25.0	-1426	-20.3613	122.1810
5	3.0	-190	196	163.0	-25.0	-1427	-16.1132	122.2552
6	3.0	-199	199	167.0	-19.0	-1426	-1.2939	123.2196
7	3.0	-197	200	167.0	-16.0	-1425	-1.1963	124.4066
8	4.0	-198	199	167.0	-20.0	-1431	-1.0986	125.2968
9	4.0	-199	199	165.0	-19.0	-1426	-1.7090	125.2226
0	4.0	-199	200	165.0	-20.0	-1428	-1.9287	124.2582
1	4.0	-196	204	160.0	-17.0	-1431	-3.4180	122.9971
2	5.0	-192	197	159.0	-25.0	-1430	-20.2880	122.1810
3	5.0	-190	196	159.0	-26.0	-1426	-15.8935	122.2552
4	5.0	-199	198	163.0	-19.0	-1426	-1.2939	123.2196
5	5.0	-198	199	162.0	-20.0	-1427	-1.1963	124.4808
6	6.0	-199	199	164.0	-20.0	-1431	-1.1230	125.2968
7	6.0	-199	200	167.0	-19.0	-1428	-1.7090	125.2226
8	6.0	-199	202	167.0	-19.0	-1426	-1.9287	124.2582
9	6.0	-197	206	163.0	-18.0	-1425	-3.3447	122.9971
0	7.0	-192	199	160.0	-26.0	-1431	-20.1660	122.1810
1	7.0	-191	198	159.0	-27.0	-1433	-15.8203	122.2552
2	7.0	-200	201	163.0	-17.0	-1431	-1.2939	123.2196
3	7.0	-198	201	164.0	-22.0	-1427	-1.1719	124.4808
4	8.0	-198	202	167.0	-20.0	-1427	-1.1230	125.2968
5	8.0	-199	202	169.0	-20.0	-1429	-1.7090	125.2226
6	8.0	-200	202	168.0	-20.0	-1431	-1.9287	124.2582
7	8.0	-200	205	166.0	-16.0	-1429	-3.2471	122.9971
8	9.0	-192	198	164.0	-26.0	-1431	-20.0683	122.1810
9	9.0	-191	200	164.0	-27.0	-1427	-15.6982	122.2552
0	9.0	-202	202	167.0	-20.0	-1430	-1.2939	123.2196
1	9.0	-198	200	168.0	-23.0	-1432	-1.1719	124.4808
2	10.0	-198	200	169.0	-21.0	-1430	-1.0986	125.2968
3	10.0	-199	199	167.0	-20.0	-1432	-1.7090	125.2226
4	10.0	-199	201	166.0	-20.0	-1431	-1.9531	124.2582
5	10.0	-201	203	163.0	-16.0	-1428	-3.2471	122.9971
6	11.0	-192	198	160.0	-26.0	-1427	-19.9951	122.1810
7	11.0	-190	196	159.0	-27.0	-1429	-15.4785	122.2552
8	11.0	-201	201	164.0	-23.0	-1431	-1.2695	123.2196
9	11.0	-199	198	167.0	-23.0	-1427	-1.1719	124.4808
0	12.0	-199	200	165.0	-22.0	-1426	-1.0986	125.2968

mber of Readings 200 No. Columns 8
ate Task Started 01/01/83 Time Task Started [illegible]

	Time Secs 1	STRING5/16 NON 2	STRING5/12 NON 3	STRING3/12 NON 4	STRING3/16 NON 5	LVDT NON 6	LOAD KN 7	STROKE MM 8
51	12.0	-199	200	166.0	-21.0	-1427	-1.7090	125.1484
52	12.0	-201	201	166.0	-21.0	-1430	-1.9531	124.1840
53	12.0	-203	205	165.0	-16.0	-1433	-3.1982	122.9971
54	13.0	-192	200	160.0	-27.0	-1427	-19.9706	122.1810
55	13.0	-191	198	156.0	-28.0	-1426	-15.3564	122.2552
56	13.0	-201	203	164.0	-24.0	-1427	-1.2695	123.2196
57	13.0	-200	200	167.0	-24.0	-1429	-1.1719	124.4808
58	14.0	-200	203	167.0	-22.0	-1429	-1.0986	125.2968
59	14.0	-200	201	169.0	-21.0	-1427	-1.7090	125.1484
60	14.0	-200	204	168.0	-20.0	-1425	-1.9287	124.2582
61	14.0	-204	202	169.0	-16.0	-1426	-3.1738	122.9971
62	15.0	-193	199	165.0	-27.0	-1425	-19.8242	122.1810
63	15.0	-192	199	162.0	-27.0	-1431	-15.3808	122.2552
64	15.0	-199	203	168.0	-24.0	-1428	-1.2695	123.2196
65	15.0	-201	200	171.0	-24.0	-1426	-1.1475	124.4808
66	16.0	-200	201	168.0	-22.0	-1428	-1.1230	125.2968
67	16.0	-199	200	167.0	-21.0	-1426	-1.7090	125.2226
68	16.0	-200	202	165.0	-20.0	-1426	-1.9531	124.2582
69	16.0	-203	203	168.0	-15.0	-1427	-3.1250	122.9971
70	17.0	-193	200	160.0	-26.0	-1429	-19.7753	122.1810
71	17.0	-192	198	161.0	-27.0	-1427	-15.2832	122.2552
72	17.0	-199	202	163.0	-24.0	-1426	-1.2695	123.2196
73	17.0	-201	198	166.0	-23.0	-1426	-1.1719	124.4808
74	18.0	-200	200	165.0	-22.0	-1432	-1.1230	125.2968
75	18.0	-200	200	168.0	-21.0	-1433	-1.7090	125.2226
76	18.0	-201	204	168.0	-20.0	-1431	-1.9287	124.1840
77	18.0	-204	204	170.0	-16.0	-1428	-3.1006	122.9971
78	19.0	-194	203	165.0	-26.0	-1426	-19.7021	122.1069
79	19.0	-193	199	162.0	-27.0	-1428	-15.0634	122.2552
80	19.0	-200	204	164.0	-23.0	-1426	-1.2695	123.2196
81	19.0	-202	202	171.0	-22.0	-1430	-1.1719	124.4808
82	20.0	-200	202	170.0	-21.0	-1426	-1.0986	125.2968
83	20.0	-200	201	171.0	-20.0	-1425	-1.7090	125.1484
84	20.0	-201	202	169.0	-19.0	-1428	-1.9531	124.1840
85	20.0	-203	203	170.0	-13.0	-1431	-3.0517	122.9971
86	21.0	-194	199	166.0	-25.0	-1431	-19.6289	122.1810
87	21.0	-193	197	165.0	-26.0	-1428	-15.0146	122.2552
88	21.0	-200	202	170.0	-21.0	-1426	-1.2695	123.2196
89	21.0	-203	200	170.0	-19.0	-1426	-1.1719	124.4808
90	22.0	-201	202	168.0	-20.0	-1430	-1.0986	125.2968
91	22.0	-201	201	167.0	-19.0	-1431	-1.7090	125.2226
92	22.0	-201	203	166.0	-18.0	-1429	-1.9287	124.1840
93	22.0	-203	204	169.0	-13.0	-1427	-3.0029	122.9971
94	23.0	-195	200	162.0	-25.0	-1426	-19.6044	122.1810
95	23.0	-192	198	159.0	-24.0	-1429	-14.9170	122.2552
96	23.0	-200	204	167.0	-19.0	-1432	-1.2695	123.2196
97	23.0	-202	201	169.0	-19.0	-1433	-1.1475	124.4808
98	24.0	-201	204	168.0	-18.0	-1427	-1.0986	125.2968
99	24.0	-201	202	170.0	-18.0	-1426	-1.7090	125.1484
100	24.0	-202	204	169.0	-17.0	-1427	[illegible]	[illegible]
101	24.0	-204	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	122.9971

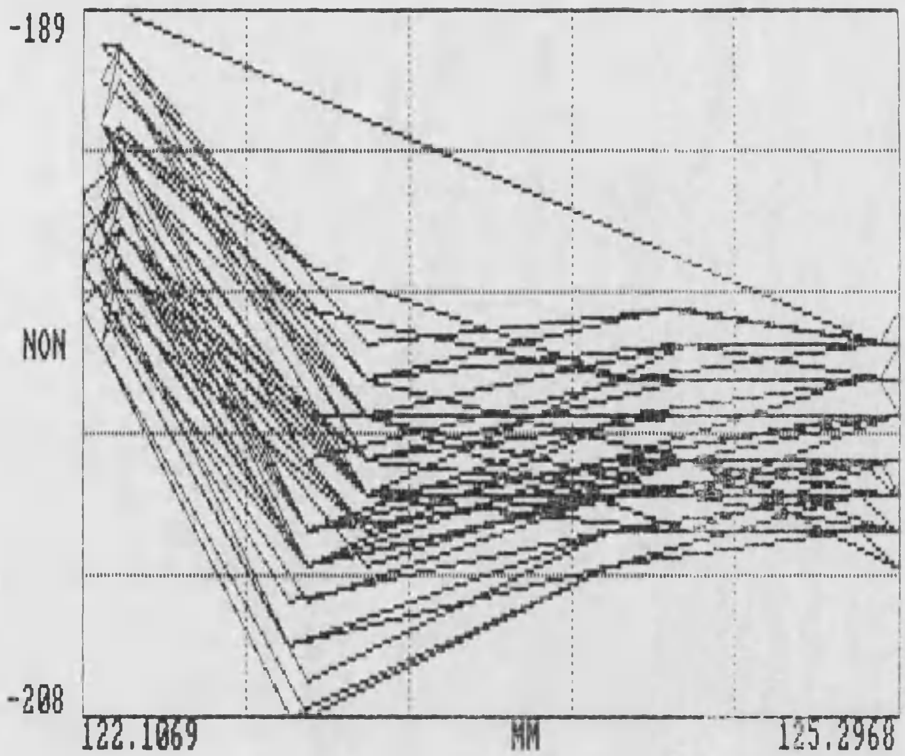
umber of Readings 200 No. Columns 8
ate Task Started 01/01/83 Time Task Started 00-23-19

	Time Secs 1	STRING5/16 NON 2	STRING5/12 NON 3	STRING3/12 NON 4	STRING3/16 NON 5	LVDT NON 6	LOAD KN 7	STROKE MM 8
102	25.0	-195	201	166.0	-25.0	-1430	19.5068	122.1810
103	25.0	-194	200	[illegible]	-24.0	-1428	14.7705	122.2552
104	25.0	-202	205	173.0	-17.0	-1426	-1.2695	123.2196
105	25.0	-203	202	173.0	-17.0	-1426	-1.1719	124.4808
106	26.0	-201	202	171.0	-19.0	-1430	-1.1230	125.2968
107	26.0	-201	201	168.0	-18.0	-1432	-1.6846	125.1484
108	26.0	-202	203	167.0	-16.0	-1432	-1.9531	124.2582
109	26.0	-204	203	171.0	-12.0	-1428	-2.9785	122.9971
110	27.0	-195	200	161.0	-23.0	-1426	-19.4335	122.1069
111	27.0	-194	199	161.0	-24.0	-1427	-14.6240	122.2552
112	27.0	-202	205	168.0	-16.0	-1430	-1.2451	123.2196
113	27.0	-202	202	168.0	-17.0	-1431	-1.1719	124.4808
114	28.0	-202	202	166.0	-18.0	-1426	-1.0986	125.2968
115	28.0	-201	201	168.0	-17.0	-1426	-1.7090	125.1484
116	28.0	-202	206	169.0	-16.0	-1426	-1.9531	124.1840
117	28.0	-203	204	173.0	-12.0	-1429	-2.9297	122.9971
118	29.0	-195	203	165.0	-22.0	-1432	-19.4335	122.1810
119	29.0	-193	199	163.0	-23.0	-1428	-14.6240	122.2552
120	29.0	-202	207	171.0	-14.0	-1426	-1.2695	123.2196
121	29.0	-202	205	171.0	-15.0	-1426	-1.1475	124.4808
122	30.0	-202	205	171.0	-18.0	-1431	-1.0986	125.2968
123	30.0	-201	201	171.0	-17.0	-1431	-1.7090	125.2226
124	30.0	-202	203	169.0	-15.0	-1428	-1.9287	124.1840
125	30.0	-205	202	173.0	-10.0	-1426	-2.9053	122.9971
126	31.0	-196	200	165.0	-22.0	-1428	-19.3115	122.1069
127	31.0	-193	197	165.0	-22.0	-1432	-14.4043	122.2552
128	31.0	-202	204	170.0	-12.0	-1433	-1.2695	123.2196
129	31.0	-202	203	167.0	-14.0	-1433	-1.1475	124.4808
130	32.0	-202	202	166.0	-17.0	-1429	-1.1230	125.2968
131	32.0	-201	201	168.0	-16.0	-1428	-1.7090	125.1484
132	32.0	-202	205	167.0	-15.0	-1429	-1.9287	124.1840
133	32.0	-204	203	172.0	-10.0	-1430	-2.8809	122.9971
134	33.0	-196	204	163.0	-21.0	-1430	-19.2626	122.1810
135	33.0	-194	200	163.0	-21.0	-1429	-14.5019	122.2552
136	33.0	-202	206	168.0	-11.0	-1428	-1.2695	123.2196
137	33.0	-201	206	170.0	-13.0	-1429	-1.1475	124.4808
138	34.0	-202	205	171.0	-15.0	-1432	-1.0986	125.2968
139	34.0	-201	202	172.0	-15.0	-1433	-1.7090	125.2226
140	34.0	-202	203	169.0	-14.0	-1433	-1.9287	124.1840
141	34.0	-204	202	174.0	-10.0	-1426	-2.8809	122.9971
142	35.0	-197	202	160.0	-19.0	-1426	-19.2138	122.1810
143	35.0	-196	199	166.0	-20.0	-1431	-14.3310	122.2552
144	35.0	-201	205	171.0	-7.0	-1431	-1.2451	123.2196
145	35.0	-202	204	168.0	-11.0	-1431	-1.1719	124.4808
146	36.0	-203	203	167.0	-14.0	-1427	-1.0986	125.2968
147	36.0	-202	203	168.0	-13.0	-1427	-1.7090	125.1484
148	36.0	-203	204	167.0	-12.0	-1432	-1.9531	124.1840
149	36.0	-205	203	171.0	-8.0	-1433	-2.8809	122.9229
150	37.0	-196	203	162.0	-18.0	-1431	-19.2138	122.1069
151	37.0	-195	200	163.0	-18.0	-1430	-14.3066	122.2552
152	37.0	-201	208	168.0	-4.0	-1429	-1.2451	123.2196

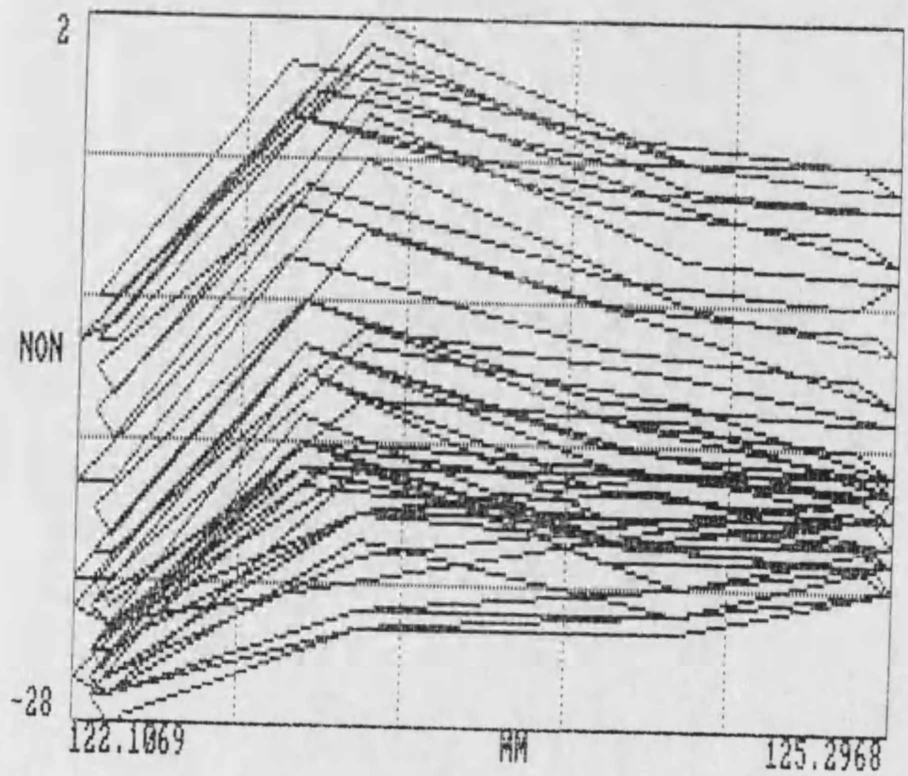
umber of Readings 200 No. Columns 8
ate Task Started 01/01/83 Time Task Started 00-23-19

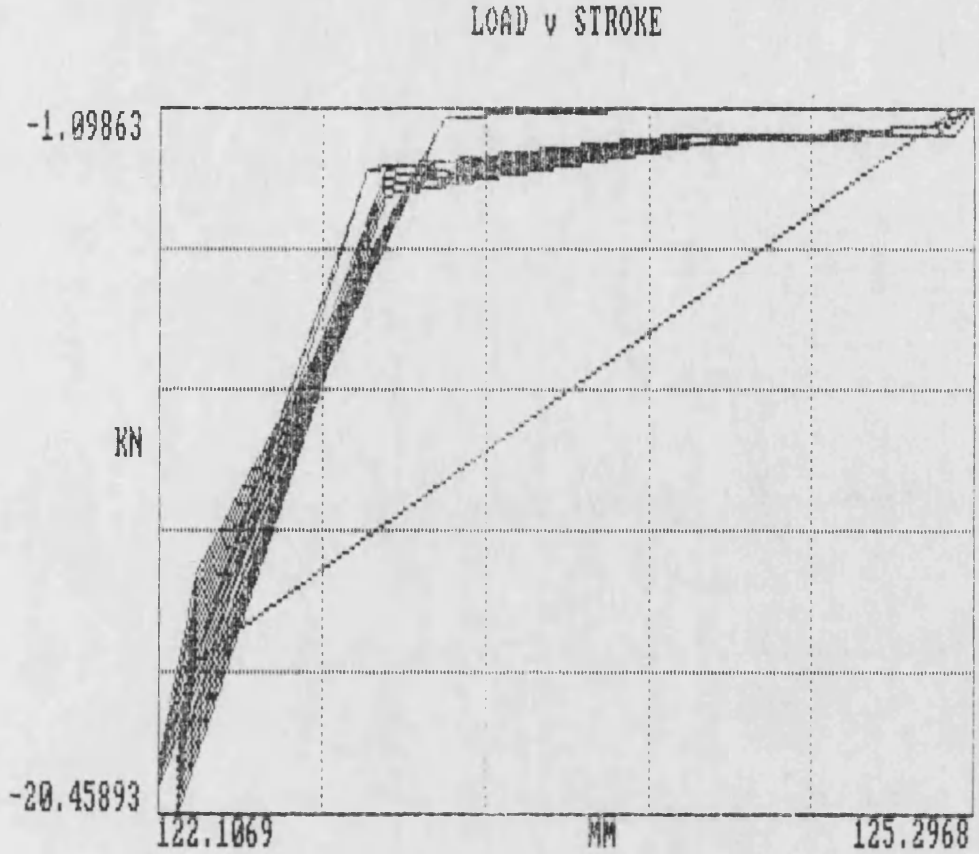
	Time Secs 1	STRING5/16 NON 2	STRING5/12 NON 3	STRING3/12 NON 4	STRING3/16 NON 5	LVDT NON 6	LOAD KN 7	STROKE MM 8
153	37.0	-202	206	168.0	-10.0	-1430	-1.1475	124.4808
154	38.0	-203	206	171.0	-12.0	-1431	-1.0986	125.2968
155	38.0	-203	202	171.0	-11.0	-1430	-1.7090	125.2226
156	38.0	-203	204	170.0	-10.0	-1429	-1.9287	124.1840
157	38.0	-206	202	173.0	-6.0	-1429	-2.8564	122.9229
158	39.0	-196	199	166.0	-15.0	-1426	-19.1162	122.1810
159	39.0	-195	200	165.0	-16.0	-1434	-14.1601	122.2552
160	39.0	-202	206	169.0	-2.0	-1433	-1.2451	123.2196
161	39.0	-201	204	167.0	-8.0	-1432	-1.1475	124.4808
162	40.0	-202	204	167.0	-9.0	-1428	-1.1230	125.2968
163	40.0	-202	202	169.0	-10.0	-1427	-1.7090	125.1484
164	40.0	-203	205	168.0	-9.0	-1432	-1.9287	124.1840
165	40.0	-207	204	171.0	-5.0	-1432	-2.8320	122.9971
166	41.0	-197	204	164.0	-13.0	-1430	-19.0429	122.1810
167	41.0	-195	201	161.0	-14.0	-1429	-14.1601	122.2552
168	41.0	-203	207	166.0	-1.0	-1430	-1.2451	123.2196
169	41.0	-201	206	169.0	-6.0	-1431	-1.1719	124.4808
170	42.0	-203	205	171.0	-8.0	-1434	-1.0986	125.2968
171	42.0	-203	203	172.0	-7.0	-1433	-1.6846	125.1484
172	42.0	-204	204	169.0	-6.0	-1432	-1.9531	124.1840
173	42.0	-206	206	173.0	-2.0	-1429	-2.9053	122.9229
174	43.0	-197	201	169.0	-12.0	-1432	-19.0429	122.1810
175	43.0	-196	199	163.0	-12.0	-1431	-14.0136	122.2552
176	43.0	-204	205	166.0	1.0	-1431	-1.2451	123.2196
177	43.0	-201	204	166.0	-5.0	-1430	-1.1719	124.4808
178	44.0	-203	204	167.0	-6.0	-1427	-1.0986	125.2968
179	44.0	-203	203	168.0	-6.0	-1434	-1.6846	125.1484
180	44.0	-204	206	168.0	-5.0	-1434	-1.9531	124.1840
181	44.0	-208	204	171.0	-2.0	-1433	-2.8076	122.9229
182	45.0	-197	205	165.0	-12.0	-1429	-18.9941	122.1069
183	45.0	-196	201	164.0	-11.0	-1428	-13.9648	122.2552
184	45.0	-203	207	161.0	2.0	-1432	-1.2451	123.2196
185	45.0	-201	205	169.0	-4.0	-1432	-1.1475	124.4808
186	46.0	-202	205	172.0	-5.0	-1429	-1.0986	125.2968
187	46.0	-202	203	172.0	-4.0	-1428	-1.7090	125.1484
188	46.0	-204	204	169.0	-4.0	-1427	-1.9287	124.1840
189	46.0	-208	203	172.0	-1.0	-1433	-2.8076	122.9971
190	47.0	-198	201	161.0	-11.0	-1428	-18.9209	122.1810
191	47.0	-196	199	164.0	-10.0	-1432	-13.8427	122.2552
192	47.0	-202	204	161.0	0.0	-1430	-1.2695	123.2196
193	47.0	-201	203	165.0	-4.0	-1429	-1.1475	124.4808
194	48.0	-204	205	167.0	-4.0	-1427	-1.0986	125.2968
195	48.0	-203	205	171.0	-4.0	-1428	-1.7090	125.1484
196	48.0	-204	206	169.0	-3.0	-1430	-1.9287	124.1840
197	48.0	-208	204	172.0	0.0	-1429	-2.8076	122.9229
198	49.0	-198	205	168.0	-10.0	-1427	-18.8964	122.1810
199	49.0	-197	204	167.0	-10.0	-1427	-13.8427	122.2552
200	49.0	-203	207	163.0	1.0	-1434	-1.2695	123.2196

STRING5/16 v STROKE



STRING3/16 v STROKE





LOAD v STROKE
-1.09863
KN
-20.45893
122.1069
MM
125.2968

umber of Readings 200 No. Columns 8
ate Task Started 01/01/83 Time Task Started 00-00-25

	Time Secs 1	STRING5/16 NON 2	STRING5/12 NON 3	STRING3/12 NON 4	STRING3/16 NON 5	LVDT NON 6	LOAD KN 7	STROKE MM 8
0	0.0	0	-16	7.0	-2.0	-1436	-1.1719	122.9229
1	0.0	2	-14	13.0	2.0	-1438	-1.1719	123.2938
2	0.0	1	-15	14.0	0.0	-1437	-1.1230	123.4422
3	0.0	1	-16	13.0	1.0	-1436	-1.0986	123.5905
4	0.0	0	-16	13.0	1.0	-1434	-1.5381	123.5905
5	0.0	0	-16	13.0	0.0	-1435	-1.7334	123.4422
6	0.0	1	-16	13.0	1.0	-1434	-1.8799	123.1454
7	0.0	0	-17	15.0	1.0	-1436	-1.9287	122.8487
8	0.0	0	-15	17.0	1.0	-1437	-1.9775	122.4778
9	1.0	-2	-17	16.0	-2.0	-1439	-2.3193	122.0327
10	1.0	5	-15	12.0	1.0	-1437	-8.6181	121.7359
11	1.0	4	-17	13.0	-3.0	-1436	-15.1123	121.4392
12	1.0	7	-19	8.0	-6.0	-1435	-20.1904	121.1425
13	1.0	9	-20	5.0	-7.0	-1434	-22.5097	121.0683
14	1.0	9	-20	4.0	-7.0	-1435	-21.2402	121.0683
15	1.0	9	-20	6.0	-6.0	-1435	-16.4550	121.2167
16	1.0	7	-18	10.0	-5.0	-1438	-10.5957	121.4392
17	1.0	4	-17	12.0	-2.0	-1438	-4.6875	121.8101
18	1.0	-1	-14	14.0	1.0	-1441	-1.2695	122.1810
19	2.0	3	-11	11.0	6.0	-1438	-1.2207	122.5520
20	2.0	0	-17	12.0	-1.0	-1441	-1.1475	122.9971
21	2.0	2	-15	12.0	2.0	-1435	-1.1475	123.2196
22	2.0	0	-17	13.0	0.0	-1434	-1.1475	123.4422
23	2.0	1	-16	12.0	1.0	-1436	-1.1230	123.5905
24	2.0	0	-16	14.0	1.0	-1436	-1.5625	123.5905
25	2.0	0	-16	14.0	1.0	-1440	-1.7578	123.4422
26	2.0	0	-16	16.0	1.0	-1439	-1.9043	123.1454
27	2.0	0	-15	15.0	1.0	-1441	-1.9287	122.8487
28	2.0	-1	-14	15.0	2.0	-1439	-1.9775	122.4778
29	3.0	-1	-18	13.0	-2.0	-1435	-2.3193	122.0327
30	3.0	4	-16	9.0	2.0	-1439	-8.5449	121.6618
31	3.0	4	-18	10.0	-5.0	-1440	-15.0390	121.3650
32	3.0	8	-20	9.0	-6.0	-1437	-20.1171	121.2167
33	3.0	9	-20	7.0	-7.0	-1437	-22.5097	121.0683
34	3.0	9	-20	8.0	-7.0	-1440	-21.0205	121.1425
35	3.0	10	-19	10.0	-7.0	-1439	-16.4550	121.2167
36	3.0	7	-19	10.0	-5.0	-1441	-10.5469	121.4392
37	3.0	4	-17	11.0	-1.0	-1439	-4.6142	121.8101
38	3.0	-2	-15	11.0	1.0	-1438	-1.2695	122.1810
39	4.0	4	-12	9.0	4.0	-1439	-1.2207	122.5520
40	4.0	-1	-18	14.0	-1.0	-1438	-1.1475	122.9229
41	4.0	1	-17	14.0	1.0	-1436	-1.1475	123.2938
42	4.0	-1	-17	16.0	1.0	-1435	-1.1230	123.4422
43	4.0	1	-16	15.0	0.0	-1435	-1.1230	123.5905
44	4.0	-1	-15	15.0	0.0	-1434	-1.5381	123.5905
45	4.0	0	-15	15.0	1.0	-1435	-1.7334	123.4422
46	4.0	0	-15	14.0	1.0	-1436	-1.9043	123.1454
47	4.0	0	-16	13.0	1.0	-1439	-1.9287	122.8487
48	4.0	-1	-16	13.0	2.0	-1439	-1.9531	122.4778
49	5.0	0	-19	12.0	-2.0	-1436	-2.2705	122.0327
50	5.0	5	-16	11.0	1.0	-1435	-8.5449	121.6618

Number of Readings 200 No. Columns 8
Date Task Started 01/01/83 Time Task Started 00-00-25

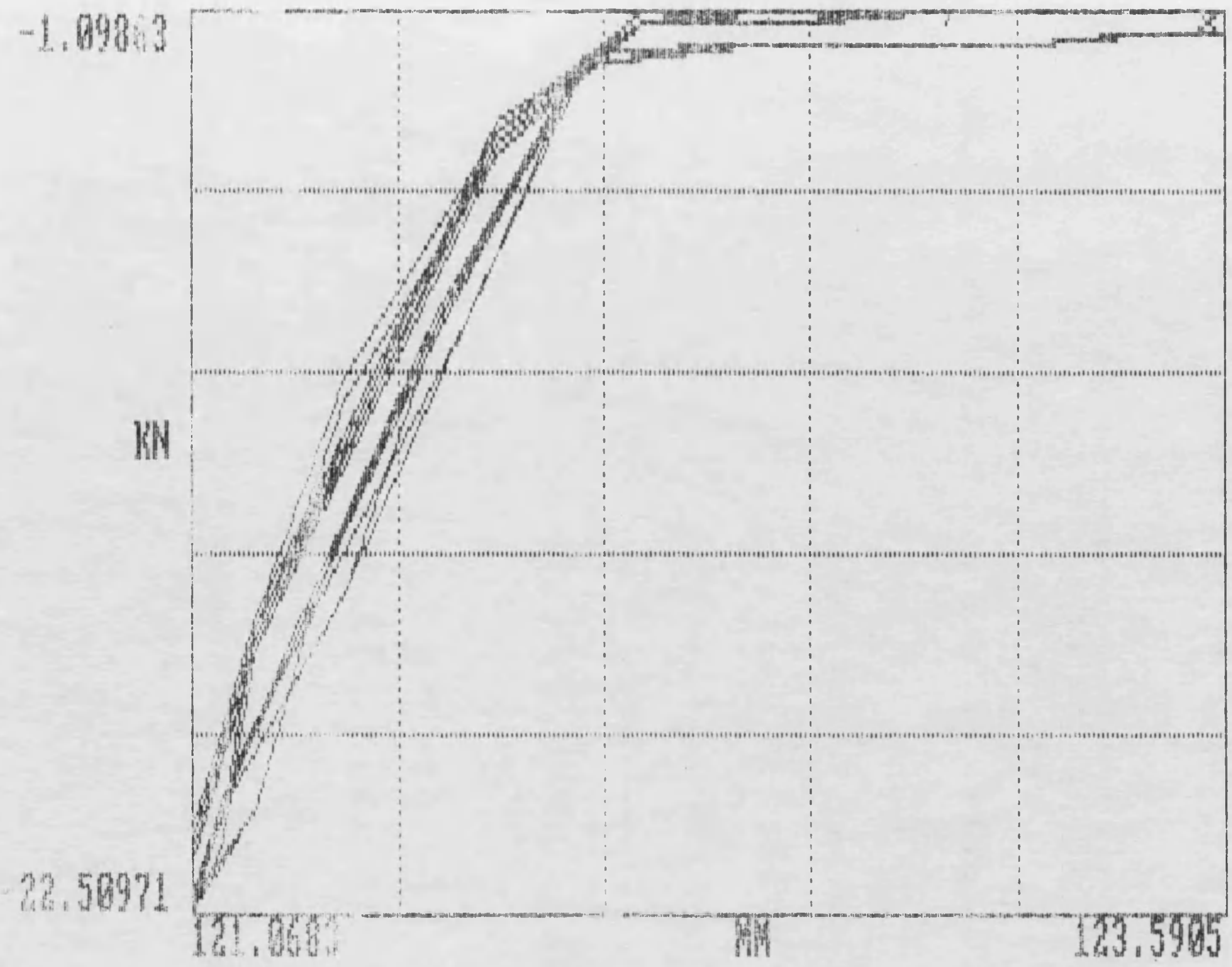
	Time Secs 1	STRING5/16 NON 2	STRING5/12 NON 3	STRING3/12 NON 4	STRING3/16 NON 5	LVDT NON 6	LOAD KN 7	STROKE MM 8
51	5.0	4	-20	13.0	-4.0	-1434	-14.9902	121.4392
52	5.0	8	-19	11.0	-5.0	-1435	-20.0683	121.1425
53	5.0	9	-19	10.0	-7.0	-1435	-22.3876	121.0683
54	5.0	9	-18	7.0	-7.0	-1437	-20.9716	121.0683
55	5.0	9	-19	6.0	-6.0	-1437	-16.3330	121.2167
56	5.0	6	-20	6.0	-4.0	-1441	-10.4736	121.5134
57	5.0	4	-17	12.0	-1.0	-1439	-4.4922	121.8101
58	5.0	-2	-17	14.0	1.0	-1441	-1.2695	122.1810
59	6.0	5	-15	10.0	4.0	-1435	-1.2695	122.5520
60	6.0	-2	-17	15.0	0.0	-1442	-1.1719	122.9971
61	6.0	1	-16	14.0	1.0	-1435	-1.1475	123.2938
62	6.0	-1	-15	16.0	1.0	-1435	-1.1230	123.5164
63	6.0	0	-16	15.0	1.0	-1438	-1.1230	123.5905
64	6.0	0	-16	15.0	1.0	-1438	-1.5381	123.5164
65	6.0	0	-16	13.0	1.0	-1441	-1.7578	123.4422
66	6.0	0	-16	13.0	1.0	-1440	-1.9043	123.1454
67	6.0	0	-17	13.0	2.0	-1441	-1.9287	122.8487
68	6.0	-1	-16	14.0	2.0	-1438	-1.9531	122.4778
69	7.0	0	-19	14.0	-1.0	-1434	-2.2705	122.0327
70	7.0	4	-16	13.0	2.0	-1436	-8.4717	121.6618
71	7.0	3	-19	14.0	-5.0	-1436	-14.9170	121.3650
72	7.0	8	-19	11.0	-5.0	-1440	-19.9951	121.1425
73	7.0	8	-19	9.0	-7.0	-1439	-22.3144	121.0683
74	7.0	9	-20	2.0	-7.0	-1441	-20.8984	121.0683
75	7.0	9	-20	7.0	-7.0	-1438	-16.2597	121.2167
76	7.0	7	-17	-1.0	-4.0	-1440	-10.1318	121.5134
77	7.0	3	-17	12.0	-1.0	-1439	-4.4433	121.8101
78	7.0	-1	-15	14.0	0.0	-1439	-1.2451	122.1810
79	8.0	4	-16	9.0	1.0	-1435	-1.2451	122.5520
80	8.0	-2	-15	18.0	0.0	-1435	-1.1963	122.9971
81	8.0	1	-16	15.0	0.0	-1439	-1.1475	123.2938
82	8.0	0	[illegible]	15.0	1.0	-1439	[illegible]	123.5164
83	8.0	1	-16	13.0	[illegible]	-1442	[illegible]	123.5164
84	8.0	1	-15	14.0	1.0	-1439	-1.5869	123.5905
85	8.0	-1	-15	13.0	1.0	-1438	[illegible]	123.4422
86	8.0	0	-15	14.0	1.0	-1438	-1.9043	123.1454
87	8.0	0	[illegible]	14.0	2.0	-1441	-1.9287	122.8487
88	[illegible]	0	-15	11.0	1.0	-1437	-1.9531	122.4778
89	9.0	0	-15	13.0	-1.0	-1439	-2.2949	122.0327
90	9.0	4	-14	10.0	1.0	-1436	-8.5937	121.7359
91	9.0	3	-14	1.0	-2.0	-1435	-15.2099	121.3650
92	9.0	7	-20	8.0	-5.0	-1435	-19.8974	121.1425
93	9.0	8	-17	6.0	-6.0	-1439	-22.2900	121.0683
94	9.0	9	-15	-1.0	-6.0	-1439	-20.5810	121.0683
95	9.0	9	-16	1.0	-7.0	-1435	-16.0644	121.2167
96	9.0	6	-16	8.0	-4.0	-1436	-10.1806	121.5134
97	9.0	3	-14	1.0	1.0	-1435	-4.0771	121.8101
98	9.0	0	-14	11.0	0.0	-1441	-1.2451	122.1810
99	10.0	3	-14	6.0	0.0	-1438	-1.2207	122.5520
100	10.0	-2	-10	6.0	3.0	-1438	-1.1963	122.9971
101	10.0	0	-14	8.0	1.0	-1441	-1.1475	123.2938

umber of Readings 200 No. Columns 8
ate Task Started 01/01/83 Time Task Started 00-00-25

	Time Secs 1	STRING5/16 NON 2	STRING5/12 NON 3	STRING3/12 NON 4	STRING3/16 NON 5	LVDT NON 6	LOAD KN 7	STROKE MM 8
02	10.0	0	-12	12.0	2.0	-1438	-1.1230	123.4422
03	10.0	0	-14	6.0	0.0	-1439	-1.1475	123.5905
04	10.0	0	-13	7.0	1.0	-1435	-1.5625	123.5164
05	10.0	0	-13	12.0	1.0	-1435	-1.7578	123.3680
06	10.0	0	-12	4.0	2.0	-1441	-1.9043	123.1454
07	10.0	-1	-14	7.0	2.0	-1435	-1.9287	122.8487
08	10.0	-1	-10	10.0	3.0	-1436	-1.9775	122.4036
09	11.0	-1	-13	6.0	1.0	-1437	-2.4414	122.0327
10	11.0	4	-13	4.0	3.0	-1439	-8.5205	121.6618
11	11.0	3	-22	10.0	-3.0	-1437	-14.9414	121.3650
12	11.0	7	-28	-3.0	-6.0	-1436	-20.0439	121.2167
13	11.0	8	-30	-2.0	-6.0	-1435	-22.2167	121.0683
14	11.0	8	-26	4.0	-6.0	-1437	-20.5810	121.0683
15	11.0	8	-33	-3.0	-5.0	-1442	-15.7959	121.2167
16	11.0	7	-35	3.0	-3.0	-1439	-10.0830	121.5134
17	11.0	2	-32	7.0	-1.0	-1439	-4.1504	121.8101
18	11.0	1	-27	7.0	0.0	-1436	-1.2451	122.1810
19	12.0	3	-28	1.0	-1.0	-1439	-1.2451	122.6262
20	12.0	-2	-20	12.0	3.0	-1441	-1.1475	122.9229
21	12.0	0	-28	3.0	0.0	-1438	-1.1475	123.2938
22	12.0	0	-27	8.0	2.0	-1442	-1.1475	123.5164
23	12.0	0	-28	12.0	1.0	-1435	-1.1230	123.5905
24	12.0	0	-28	7.0	1.0	-1436	-1.5869	123.5164
25	12.0	0	-29	5.0	2.0	-1441	-1.7334	123.4422
26	12.0	-1	-26	9.0	2.0	-1435	-1.9287	123.1454
27	12.0	-1	-24	2.0	2.0	-1438	-1.9287	122.8487
28	12.0	-1	-25	6.0	3.0	-1437	-1.9775	122.4778
29	13.0	1	-24	8.0	0.0	-1440	-2.2949	122.0327
30	13.0	4	-24	1.0	1.0	-1435	-8.8135	121.6618
31	13.0	3	-22	1.0	-3.0	-1438	-14.8925	121.3650
32	13.0	7	-28	7.0	-5.0	-1435	-19.8486	121.1425
33	13.0	8	-28	-4.0	-6.0	-1436	-22.1679	121.0683
34	13.0	9	-31	-2.0	-7.0	-1436	-20.5078	121.0683
35	13.0	8	-32	1.0	-5.0	-1435	-15.8447	121.2167
36	13.0	5	-26	-1.0	-3.0	-1439	-9.7900	121.5134
37	13.0	2	-33	-3.0	0.0	-1440	-4.1992	121.8101
38	13.0	1	-30	11.0	0.0	-1440	-1.2451	122.1810
39	14.0	1	-36	0.0	-2.0	-1436	-1.2207	122.6262
40	14.0	-2	-32	9.0	3.0	-1435	-1.1719	122.9971
41	14.0	0	-36	8.0	0.0	-1441	-1.1475	123.2938
42	14.0	0	-35	5.0	2.0	-1438	-1.1475	123.5164
43	14.0	-1	-35	3.0	1.0	-1440	-1.1230	123.5905
44	14.0	0	-31	9.0	1.0	-1435	-1.5869	123.5905
45	14.0	-1	-28	6.0	1.0	-1437	-1.7334	123.3680
46	14.0	0	-29	8.0	2.0	-1439	-1.9043	123.1454
47	14.0	-1	-23	9.0	2.0	-1440	-1.9287	122.8487
48	14.0	-1	-21	5.0	3.0	-1437	-1.9775	122.4036
49	15.0	3	-19	6.0	-1.0	-1434	-2.2705	122.0327
50	15.0	3	-18	7.0	1.0	-1437	-8.4472	121.6618
51	15.0	2	-19	4.0	-2.0	-1435	-15.0634	121.3650
52	15.0	8	-20	1.0	-6.0	-1435	-19.7753	121.1425

Number of Readings 200 No. Columns 8
Date Task Started 01/01/83 Time Task Started 00-00-25

	Time Secs 1	STRING5/16 NON 2	STRING5/12 NON 3	STRING3/12 NON 4	STRING3/16 NON 5	LVDT NON 6	LOAD KN 7	STROKE MM 8
153	15.0	7	-22	8.0	-6.0	-1439	-22.0458	121.0683
154	15.0	9	-18	-3.0	-7.0	-1439	-20.3613	121.1425
155	15.0	8	-19	-4.0	-6.0	-1436	-15.7714	121.2167
156	15.0	5	-18	6.0	-3.0	-1439	-9.8877	121.5134
157	15.0	2	-17	0.0	0.0	-1438	-3.8330	121.8101
158	15.0	1	-14	6.0	1.0	-1439	-1.2451	122.1810
159	16.0	1	-20	10.0	-3.0	-1437	-1.2451	122.6262
160	16.0	0	-14	6.0	3.0	-1435	-1.1475	122.9971
161	16.0	-1	-16	7.0	0.0	-1436	-1.1475	123.2938
162	16.0	0	-13	9.0	2.0	-1435	-1.1230	123.4422
163	16.0	0	-15	4.0	2.0	-1441	-1.1475	123.5905
164	16.0	0	-15	8.0	1.0	-1439	-1.5625	123.5905
165	16.0	-1	-15	10.0	1.0	-1440	-1.7334	123.3680
166	16.0	-1	-16	3.0	2.0	-1439	-1.9287	123.1454
167	16.0	-1	-12	6.0	3.0	-1436	-1.9287	122.8487
168	16.0	-1	-13	9.0	3.0	-1441	-1.9775	122.4778
169	17.0	0	-15	3.0	-1.0	-1435	-2.3437	122.0327
170	17.0	2	-13	4.0	2.0	-1436	-8.3984	121.6618
171	17.0	3	-15	8.0	-4.0	-1435	-14.8193	121.3650
172	17.0	7	-16	-4.0	-5.0	-1442	-19.8486	121.1425
173	17.0	8	-16	3.0	-6.0	-1436	-22.0458	121.0683
174	17.0	8	-17	-5.0	-6.0	-1442	-20.4345	121.0683
175	17.0	6	-19	-5.0	-4.0	-1441	-15.4541	121.2167
176	17.0	5	-16	-1.0	-3.0	-1439	-9.8633	121.4392
177	17.0	2	-14	6.0	-1.0	-1441	-3.9795	121.8101
178	17.0	0	-14	6.0	6.0	-1436	-1.2207	122.1810
179	18.0	0	-19	5.0	-3.0	-1435	-1.2207	122.6262
180	18.0	-1	-12	9.0	4.0	-1436	1.1719	122.9971
181	18.0	-1	-15	6.0	2.0	-1434	-1.1475	123.2938
182	[illegible]	0	-13	8.0	[illegible]	-1439	-1.1475	123.5164
183	18.0	-1	-15	10.0	[illegible]	[illegible]	[illegible]	123.5905
[illegible]	[illegible]	-1	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	123.4422
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1.0	-1439	-1.9043	123.1454
[illegible]	[illegible]	[illegible]	[illegible]	6.0	3.0	-1435	-1.9531	122.7745
[illegible]	18.0	-2	-13	8.0	2.0	-1435	-1.9775	122.4778
189	19.0	2	-15	14.0	0.0	-1435	-2.2705	122.0327
190	19.0	3	-12	1.0	1.0	-1438	-8.6914	121.6618
191	19.0	2	-17	5.0	-3.0	-1439	-14.7461	121.3650
192	19.0	6	-17	7.0	-5.0	-1436	-19.7021	121.1425
193	19.0	8	-18	-6.0	-5.0	-1441	-21.9238	121.0683
194	19.0	8	-17	-5.0	-6.0	-1438	-20.3125	121.0683
195	19.0	8	-14	-4.0	-5.0	-1441	-15.6005	121.2167
196	19.0	6	-16	1.0	-3.0	-1438	-9.5703	121.5134
197	19.0	2	-13	4.0	1.0	-1435	-3.9795	121.8101
198	19.0	-1	-11	11.0	3.0	-1438	-1.2451	122.1810
199	20.0	-2	-16	9.0	0.0	-1438	-1.2451	122.6262
200	20.0	0	-10	8.0	4.0	-1437	-1.1719	122.9971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KN
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MM
123.5905

umber of Readings 200 No. Columns 8

ate Task Started 01/01/83 Time Task Started 00-11-38

	Time Secs 1	STRING5/16 MM 2	STRING5/12 MM 3	STRING3/12 MM 4	STRING3/16 MM 5	LVDT NON 6	LOAD KN 7	STROKE MM 8
0	0.0	0.3492	-0.3290	-1.0155	0.8531	-1	-4.4922	113.6499
1	0.0	0.3004	-0.2935	-0.9531	0.9019	-1	-1.5381	114.0208
2	0.0	0.2934	-0.2668	-1.1046	0.9019	-1	-1.4404	114.0208
3	0.0	0.2794	-0.2757	-0.9710	0.9181	-1	-1.1475	114.0208
4	1.0	0.2724	-0.2757	-0.9531	0.9181	-1	-1.2207	114.0950
5	1.0	0.2724	-0.2757	-0.9531	0.9262	-1	-2.1484	114.0208
6	2.0	0.2794	-0.2846	-0.9531	0.9181	-2	-4.1992	113.8724
7	2.0	0.2934	-0.2846	-0.9620	0.9181	-2	-7.1289	113.7241
8	3.0	0.3073	-0.2935	-0.9799	0.8938	-2	-10.8886	113.5015
9	3.0	0.3283	-0.3113	-1.0155	0.8656	-2	-15.2099	113.2790
10	4.0	0.3562	-0.3379	-1.0422	0.8531	-2	-19.8486	113.0564
11	4.0	0.3842	-0.3646	-1.0511	0.8288	-2	-24.0478	112.9081
12	5.0	0.4121	-0.3913	-1.0778	0.7962	-2	-27.0263	112.7597
13	5.0	0.4331	-0.4002	-1.0957	0.7800	-2	-28.2226	112.6855
14	6.0	0.4401	-0.3913	-1.1046	0.7800	-2	-27.8564	112.6855
15	6.0	0.4401	-0.3824	-1.2026	0.7719	-1	-24.3163	112.7597
16	7.0	0.4261	-0.4091	-1.0868	0.7800	-1	-19.9951	112.9081
17	7.0	0.4051	-0.3913	-1.0957	0.7881	-1	-15.3320	113.0564
18	8.0	0.3912	-0.3646	-1.0689	0.8125	-1	-10.7666	113.2790
19	8.0	0.3562	-0.3646	-1.0511	0.8288	-1	-7.0312	113.5015
20	9.0	0.3283	-0.3290	-1.0244	0.8531	-1	-4.1260	113.6499
21	9.0	0.3004	-0.2935	-1.0066	0.8856	-1	-2.1484	113.8724
22	10.0	0.2794	-0.2668	-0.9710	0.9100	-1	-1.2207	113.9466
23	10.0	0.2724	-0.2490	-0.9620	0.9181	-1	-0.9521	114.0950
24	11.0	0.2724	-0.2134	-0.9620	0.9262	-2	-1.0254	114.0208
25	11.0	0.2794	-0.1601	-0.9620	0.9262	-2	-1.7822	114.0208
26	12.0	0.2794	-0.1779	-0.9710	0.9262	-2	-3.7598	113.8724
27	12.0	0.2864	-0.1868	-0.9710	0.9100	-2	-6.6162	113.7241
28	13.0	0.3004	-0.1956	-1.0066	0.8938	-2	-10.3027	113.5015
29	13.0	0.3213	-0.2134	-1.0333	0.8856	-2	-14.5752	113.2790
30	14.0	0.3492	-0.2490	-1.0244	0.8612	-2	-19.1162	113.0564
31	14.0	0.3772	-0.2668	-1.0778	0.8288	-2	-23.2910	112.9081
32	15.0	0.4051	-0.2846	-1.0957	0.8044	-1	-26.2939	112.7597
33	15.0	0.4191	-0.3024	-1.1046	0.7881	-2	-27.6855	112.6855
34	16.0	0.4261	-0.3024	-1.0957	0.7881	-1	-27.3193	112.6855
35	16.0	0.4261	-0.3024	-1.1046	0.7881	-1	-23.8036	112.7597
36	17.0	0.4191	-0.3024	-1.1046	0.7881	-1	-19.4580	112.9081
37	17.0	0.3981	-0.2846	-1.0689	0.8044	-1	-14.9414	113.0564
38	18.0	0.3772	-0.2757	-1.0600	0.8206	-1	-10.4492	113.2790
39	18.0	0.3492	-0.2668	-1.0422	0.8531	-1	-6.7139	113.5015
40	19.0	0.3143	-0.2401	-1.0244	0.8775	-1	-3.8574	113.6499
41	19.0	0.2934	-0.2223	-0.9977	0.8938	-1	-1.9287	113.8724
42	20.0	0.2794	-0.2134	-0.9620	0.9181	-1	-1.0986	114.0208
43	20.0	0.2724	-0.2223	-0.9531	0.9262	-1	-0.8545	114.0950
44	21.0	0.2724	-0.2134	-0.9620	0.9344	-2	-0.9277	114.0950
45	21.0	0.2724	-0.2223	-0.9531	0.9262	-2	-1.5869	114.0208
46	22.0	0.2724	-0.2312	-0.9620	0.9262	-2	-3.4424	113.8724
47	22.0	0.2794	-0.2223	-0.9799	0.9181	-2	-6.2988	113.7241
48	23.0	0.3004	-0.2312	-0.9977	0.9100	-2	-9.9609	113.5015
49	23.0	0.3213	-0.2579	-1.0244	0.8656	-2	-14.1357	113.2790
50	24.0	0.3492	-0.2668	-1.0689	0.8612	-2	-18.6279	113.0564

Number of Readings 200 No. Columns 8

Date Task Started 01/01/83 Time Task Started 00-11-38

	Time Secs 1	STRING5/16 MM 2	STRING5/12 MM 3	STRING3/12 MM 4	STRING3/16 MM 5	LVDT NON 6	LOAD KN 7	STROKE MM 8
51	24.0	0.3772	-0.3024	-1.0689	0.8369	-2	-22.7783	112.9081
52	25.0	0.3981	-0.3290	-1.0957	0.8206	-2	-25.8056	112.7597
53	25.0	0.4051	-0.3468	-1.1046	0.7962	-1	-27.1972	112.6855
54	26.0	0.4191	-0.3379	-1.0778	0.7962	-1	-26.8798	112.6855
55	26.0	0.4261	-0.3468	-1.1135	0.7962	-1	-23.3886	112.7597
56	27.0	0.4051	-0.3379	-1.0868	0.8044	-1	-19.1650	112.9081
57	27.0	0.3912	-0.3290	-1.1046	0.8125	-1	-14.6484	113.0564
58	28.0	0.3702	-0.3201	-1.0600	0.8369	-1	-10.2051	113.2790
59	28.0	0.3423	-0.2935	-1.0333	0.8531	-1	-6.4941	113.4273
60	29.0	0.3143	-0.2757	-1.0155	0.8775	-1	-3.6865	113.6499
61	29.0	0.2864	-0.2579	-0.9977	0.9019	-1	-1.7822	113.8724
62	30.0	0.2794	-0.2490	-0.9888	0.9181	-1	-0.9766	114.0208
63	30.0	0.2654	-0.2401	-0.9710	0.9262	-2	-0.7568	114.0208
64	31.0	0.2724	-0.2490	-0.9531	0.9262	-2	-0.8545	114.0950
65	31.0	0.2654	-0.2401	-0.9531	0.9344	-2	-1.4893	114.0208
66	32.0	0.2654	-0.2490	-0.9442	0.9262	-2	-3.2226	113.8724
67	32.0	0.2794	-0.2490	-0.9888	0.9262	-2	-6.1279	113.7241
68	33.0	0.3004	-0.2490	-1.0066	0.9100	-2	-9.7168	113.5015
69	33.0	0.3213	-0.2846	-1.0244	0.8856	-2	-13.8183	113.2790
70	34.0	0.3423	-0.2846	-1.0689	0.8694	-2	-18.3837	113.0564
71	34.0	0.3702	-0.3201	-1.0600	0.8369	-2	-22.3388	112.9081
72	35.0	0.3912	-0.3201	-1.0868	0.8206	-1	-25.4394	112.7597
73	35.0	0.4121	-0.3379	-1.1046	0.8125	-1	-26.7822	112.6855
74	36.0	0.4121	-0.3468	-1.1135	0.8044	-1	-26.5136	112.6855
75	36.0	0.4121	-0.3468	-1.1046	0.8044	-1	-22.9736	112.7597
76	37.0	0.3981	-0.3379	-1.0868	0.8044	-1	-18.9453	112.8339
77	37.0	0.3842	-0.3379	-1.0689	0.8288	-1	-14.4531	113.0564
78	38.0	0.3632	-0.3201	-1.0511	0.8450	-1	-10.0586	113.2790
79	38.0	0.3353	-0.2935	-1.0244	0.8612	-1	-6.3476	113.4273
80	39.0	0.3073	-0.2846	-1.0244	0.8856	-1	-3.5400	113.6499
81	39.0	0.2864	-0.2668	-0.9977	0.9100	-1	-1.6602	113.7983
82	40.0	0.2724	-0.2668	-0.9888	0.9262	-1	-0.9277	114.0208
83	40.0	0.2584	-0.2668	-0.9531	0.9262	-2	-0.7324	114.0208
84	41.0	0.2654	-0.2668	-0.9531	0.9344	-2	-0.8057	114.0950
85	41.0	0.2654	-0.2668	-0.9531	0.9344	-2	-1.3916	114.0208
86	42.0	0.2724	-0.2668	-0.9531	0.9344	-2	-3.0273	113.8724
87	42.0	0.2794	-0.2668	-0.9888	0.9262	-2	-5.9814	113.7241
88	43.0	0.2934	-0.2846	-1.0066	0.9100	-2	-9.4970	113.5015
89	43.0	0.3143	-0.3113	-1.0066	0.8938	-2	-13.5742	113.2790
90	44.0	0.3423	-0.3201	-1.0511	0.8694	-2	-18.0664	113.0564
91	44.0	0.3772	-0.3290	-1.0600	0.8531	-1	-22.0214	112.9081
92	45.0	0.3842	-0.3557	-1.0689	0.8288	-1	-25.0976	112.7597
93	45.0	0.3981	-0.3557	-1.1046	0.8044	-1	-26.5624	112.6855
94	46.0	0.4051	-0.3646	-1.1046	0.8125	-1	-26.1474	112.6855
95	46.0	0.4051	-0.3735	-1.1046	0.8044	-1	-22.7783	112.7597
96	47.0	0.3912	-0.3735	-1.0333	0.8206	-1	-18.7011	112.8339
97	47.0	0.3772	-0.3557	-1.0778	0.8288	-1	-14.3066	113.0564
98	48.0	0.3562	-0.3290	-1.0511	0.8450	-1	-9.9121	113.2048
99	48.0	0.3353	-0.3113	-1.0333	0.8694	-1	-6.2500	113.4273
100	49.0	0.3073	-0.2935	-1.0155	0.8856	-1	-3.4180	113.7241
101	49.0	0.2864	-0.3024	-0.9888	0.9181	-2	-1.6113	113.8724

umber of Readings 200 No. Columns 8

ate Task Started 01/01/83 Time Task Started 00-11-38

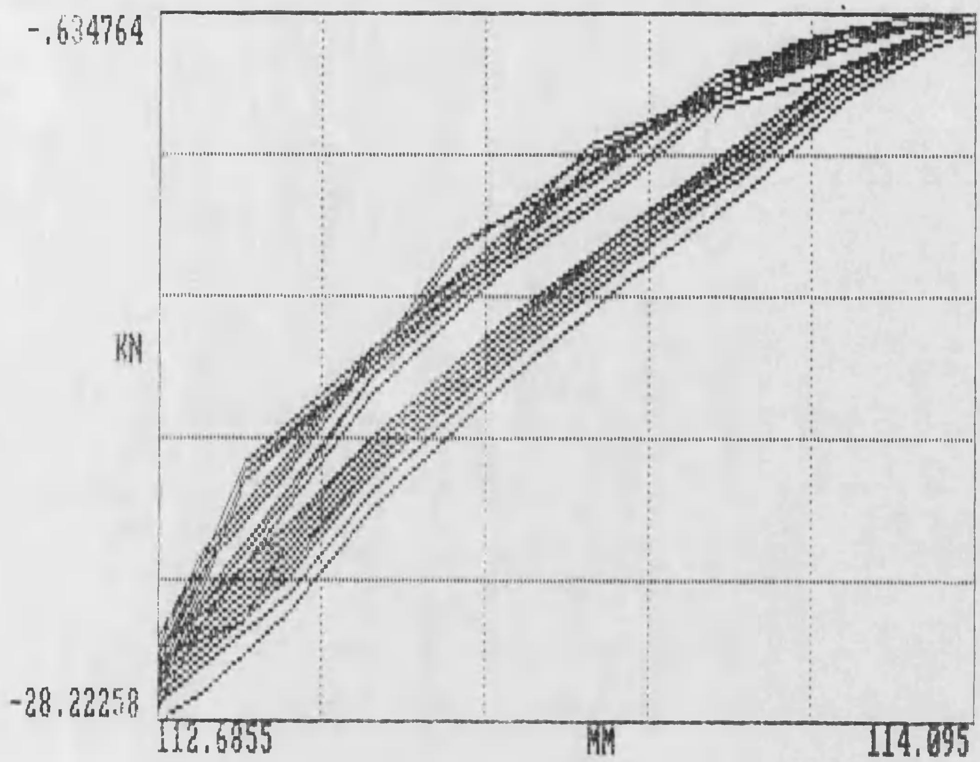
	Time Secs 1	STRING5/16 MM 2	STRING5/12 MM 3	STRING3/12 MM 4	STRING3/16 MM 5	LVDT NON 6	LOAD KN 7	STROKE MM 8
102	50.0	0.2724	-0.2668	-0.9620	0.9262	-1	-0.8789	114.0208
103	50.0	0.2654	-0.2490	-0.9710	0.9344	-2	-0.7080	114.0208
104	51.0	0.2654	-0.2312	-0.9531	0.9344	-2	-0.7568	114.0950
105	51.0	0.2654	-0.2134	-0.9531	0.9425	-2	-1.3428	114.0208
106	52.0	0.2654	-0.1779	-0.9710	0.9425	-2	-2.9297	113.8724
107	.52.0	0.2794	-0.1868	-0.9888	0.9262	-2	-5.7861	113.7241
108	53.0	0.2864	-0.2045	-0.9977	0.9181	-2	-9.3261	113.5015
109	53.0	0.3143	-0.2223	-1.0244	0.8938	-2	-13.3789	113.2790
110	54.0	0.3353	-0.2312	-1.0422	0.8694	-2	-17.7978	113.0564
111	54.0	0.3562	-0.2579	-1.0600	0.8531	-1	-21.7285	112.9081
112	55.0	0.3772	-0.2668	-1.1046	0.8369	-1	-24.8290	112.7597
113	55.0	0.3912	-0.2935	-1.0957	0.8206	-1	-26.3183	112.6855
114	56.0	0.3981	-0.2935	-1.1046	0.8125	-1	-25.9521	112.6855
115	56.0	0.3981	-0.3024	-1.1046	0.8125	-1	-22.5341	112.7597
116	57.0	0.3842	-0.3201	-1.0422	0.8125	-1	-18.5546	112.8339
117	57.0	0.3772	-0.2846	-1.0778	0.8369	-1	-14.1601	113.0564
118	58.0	0.3562	-0.2757	-1.0511	0.8450	-1	-9.8633	113.2790
119	58.0	0.3283	-0.2490	-1.0244	0.8694	-1	-6.1523	113.5015
120	59.0	0.3004	-0.2401	-1.0155	0.8938	-1	-3.2959	113.6499
121	59.0	0.2794	-0.2401	-0.9888	0.9181	-2	-1.5381	113.8724
122	60.0	0.2724	-0.2223	-0.9710	0.9262	-2	-0.8545	114.0208
123	60.0	0.2584	-0.2223	-0.9531	0.9344	-2	-0.6592	114.0950
124	61.0	0.2584	-0.2223	-0.9531	0.9425	-2	-0.7324	114.0208
125	61.0	0.2584	-0.2134	-0.9710	0.9425	-2	-1.2939	114.0208
126	62.0	0.2654	-0.2134	-0.9710	0.9425	-2	-2.8076	113.8724
127	62.0	0.2794	-0.2312	-0.9888	0.9262	-2	-5.5664	113.7241
128	63.0	0.2934	-0.2490	-0.9977	0.9181	-2	-9.1797	113.5015
129	63.0	0.3073	-0.2579	-1.0155	0.8938	-2	-13.1103	113.2790
130	64.0	0.3353	-0.2846	-1.0244	0.8775	-1	-17.6269	113.0564
131	64.0	0.3562	-0.2935	-1.0600	0.8531	-1	-21.4599	112.9081
132	65.0	0.3772	-0.3113	-1.0868	0.8450	-1	-24.4628	112.7597
133	65.0	0.3912	-0.3113	-1.0957	0.8206	-1	-26.0009	112.6855
134	66.0	0.3981	-0.3201	-1.1046	0.8206	-1	-25.7568	112.6855
135	66.0	0.3981	-0.3290	-1.1046	0.8206	-1	-22.3144	112.7597
136	67.0	0.3842	-0.3113	-1.1135	0.8288	-1	-18.4082	112.9081
137	67.0	0.3702	-0.2935	-1.0689	0.8450	-1	-14.0136	113.0564
138	68.0	0.3492	-0.2846	-1.0422	0.8531	-1	-9.7168	113.2048
139	68.0	0.3213	-0.2668	-1.0244	0.8694	-1	-6.0303	113.5015
140	69.0	0.3004	-0.2579	-1.0066	0.9019	-1	-3.2226	113.6499
141	69.0	0.2794	-0.2401	-0.9888	0.9181	-2	-1.4648	113.8724
142	70.0	0.2654	-0.2401	-0.9620	0.9262	-2	-0.8057	114.0208
143	70.0	0.2584	-0.2401	-0.9531	0.9425	-2	-0.6592	114.0208
144	71.0	0.2584	-0.2312	-0.9531	0.9425	-2	-0.7324	114.0208
145	71.0	0.2584	-0.2312	-0.9620	0.9425	-2	-1.2451	114.0208
146	72.0	0.2654	-0.2223	-0.9710	0.9506	-2	-2.7100	113.8724
147	72.0	0.2724	-0.2490	-0.9888	0.9344	-2	-5.3955	113.7241
148	73.0	0.2864	-0.2579	-0.9977	0.9181	-2	-9.9844	113.5015
149	73.0	0.3073	-0.2668	-1.0244	0.9019	-2	-13.0127	113.2790
150	74.0	0.3353	-0.2757	-1.0333	0.8856	-1	-17.3626	113.0564
151	74.0	0.3562	-0.2935	-1.0689	0.8612	-1	[illegible]	112.9081
152	75.0	0.3702	[illegible]	-1.0777	[illegible]	-1	[illegible]	[illegible]

umber of Readings 200 No. Columns 8

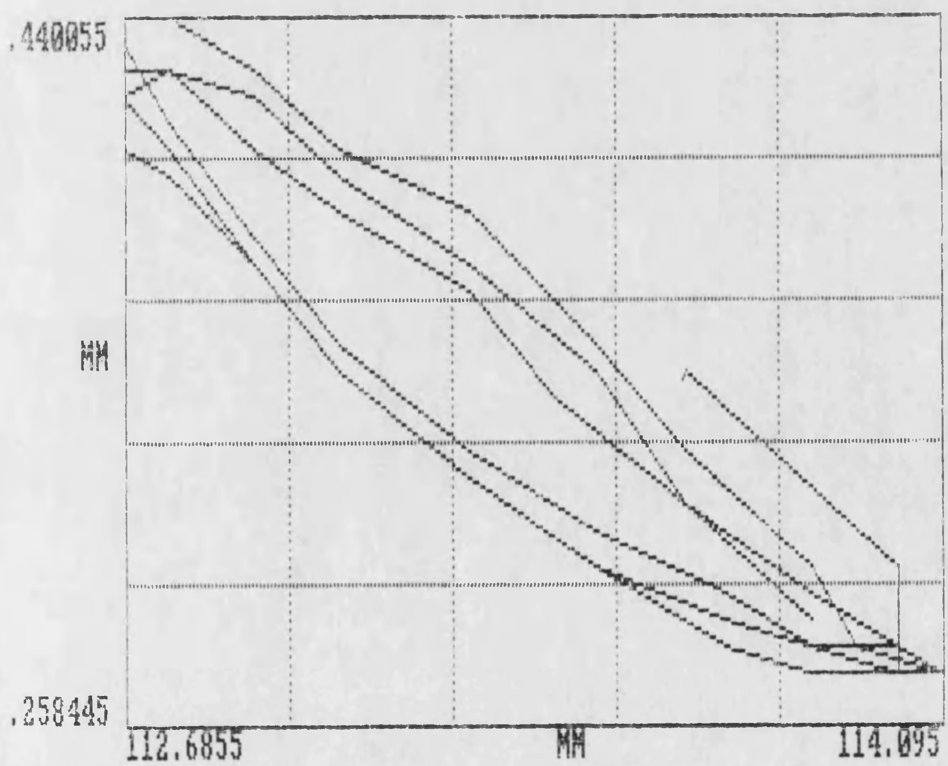
ate Task Started 01/01/83 Time Task Started 00-11-38

	Time Secs 1	STRING5/16 MM 2	STRING5/12 MM 3	STRING3/12 MM 4	STRING3/16 MM 5	LVDT NON 6	LOAD KN 7	STROKE MM 8
153	75.0	0.3842	-0.3290	-1.1046	0.8369	-1	-25.7812	112.6855
154	76.0	0.3912	-0.3290	-1.1135	0.8288	-1	-25.4882	112.6855
155	76.0	0.3842	-0.3290	-1.0957	0.8206	-1	-22.1679	112.7597
156	77.0	0.3772	-0.3201	-1.0778	0.8288	-1	-18.2373	112.8339
157	77.0	0.3702	-0.3024	-1.0778	0.8450	-1	-13.8672	113.0564
158	78.0	0.3492	-0.2935	-1.0511	0.8612	-1	-9.5947	113.2790
159	78.0	0.3213	-0.2757	-1.0244	0.8775	-1	-5.9326	113.5015
160	79.0	0.2934	-0.2579	-1.0155	0.9100	-1	-3.1250	113.6499
161	79.0	0.2654	-0.2579	-0.9888	0.9262	-2	-1.4160	113.8724
162	80.0	0.2654	-0.2579	-0.9710	0.9344	-2	-0.7812	114.0208
163	80.0	0.2584	-0.2579	-0.9531	0.9506	-2	-0.6348	114.0208
164	81.0	0.2654	-0.2490	-0.9442	0.9425	-2	-0.7568	114.0950
165	81.0	0.2584	-0.2490	-0.9442	0.9506	-2	-1.1963	114.0208
166	82.0	0.2724	-0.2490	-0.9531	0.9506	-2	-2.5635	113.8724
167	82.0	0.2724	-0.2490	-0.9710	0.9425	-2	-5.2734	113.7241
168	83.0	0.2864	-0.2668	-0.9888	0.9262	-2	-8.7646	113.5015
169	83.0	0.3073	-0.2935	-0.9977	0.9100	-2	-12.8174	113.2790
170	84.0	0.3353	-0.3024	-0.9710	0.8856	-2	-17.1875	113.0564
171	84.0	0.3562	-0.3113	-0.9888	0.8694	-2	-21.0205	112.9081
172	85.0	0.3702	-0.3290	-1.0600	0.8531	-1	-24.0478	112.7597
173	85.0	0.3842	-0.3379	-1.0689	0.8450	-1	-25.5370	112.6855
174	86.0	0.3912	-0.3468	-1.0868	0.8369	-1	-25.2197	112.6855
175	86.0	0.3912	-0.3379	-1.0778	0.8369	-1	-21.9482	112.7597
176	87.0	0.3842	-0.3379	-1.0778	0.8450	-1	-18.0908	112.9081
177	87.0	0.3702	-0.3290	-1.0511	0.8531	-1	-13.7207	113.0564
178	88.0	0.3423	-0.3113	-1.0244	0.8694	-1	-9.4726	113.2790
179	88.0	0.3143	-0.2846	-1.0155	0.8856	-2	-5.7861	113.4273
180	89.0	0.2934	-0.2668	-1.0868	0.9181	-2	-3.0517	113.7241
181	89.0	0.2724	-0.2668	-0.9799	0.9344	-1	-1.3916	113.8724
182	90.0	0.2654	-0.2490	-0.9710	0.9425	-2	-0.7568	114.0208
183	90.0	0.2584	-0.2134	-1.0511	0.9588	-2	-0.6348	114.0950
184	91.0	0.2584	-0.1956	-0.9710	0.9588	-2	-0.7324	114.0208
185	91.0	0.2584	-0.1956	-0.9531	0.9506	-2	-1.1719	114.0208
186	92.0	0.2584	-0.1779	-1.0422	0.9506	-2	-2.5391	113.8724
187	92.0	0.2654	-0.2045	-0.9799	0.9425	-2	-5.1269	113.7241
188	93.0	0.2864	-0.2045	-0.9977	0.9344	-1	-8.7402	113.5015
189	93.0	0.3143	-0.2134	-1.0957	0.9181	-2	-12.6709	113.2790
190	94.0	0.3353	-0.2312	-1.0422	0.8938	-1	-17.0654	113.0564
191	94.0	0.3423	-0.2579	-1.0689	0.8775	-1	-20.7763	112.9081
192	95.0	0.3702	-0.2490	[illegible]	0.8612	-1	-23.8525	112.7597
193	95.0	0.3772	-0.2846	-1.0957	0.8450	-1	-25.4150	112.6855
194	96.0	0.3842	-0.2935	-1.1046	0.8369	-1	-24.9999	112.6855
195	96.0	0.3912	-0.2757	[illegible]	0.8450	-1	-21.7773	112.7597
196	97.0	[illegible]	-0.2757	-1.0778	0.8531	-1	-17.9199	112.9081
197	97.0	0.3562	-0.2846	-1.0511	0.8612	-1	-13.5986	113.0564
198	98.0	0.3423	-0.2401	-1.1224	0.8775	-2	-9.3261	113.2790
199	98.0	0.3143	-0.2401	-1.0244	0.9019	-1	-5.7373	113.5015
200	99.0	0.2864	-0.2223	-0.9977	0.9181	-1	-3.0029	113.6499

LOAD v STROKE

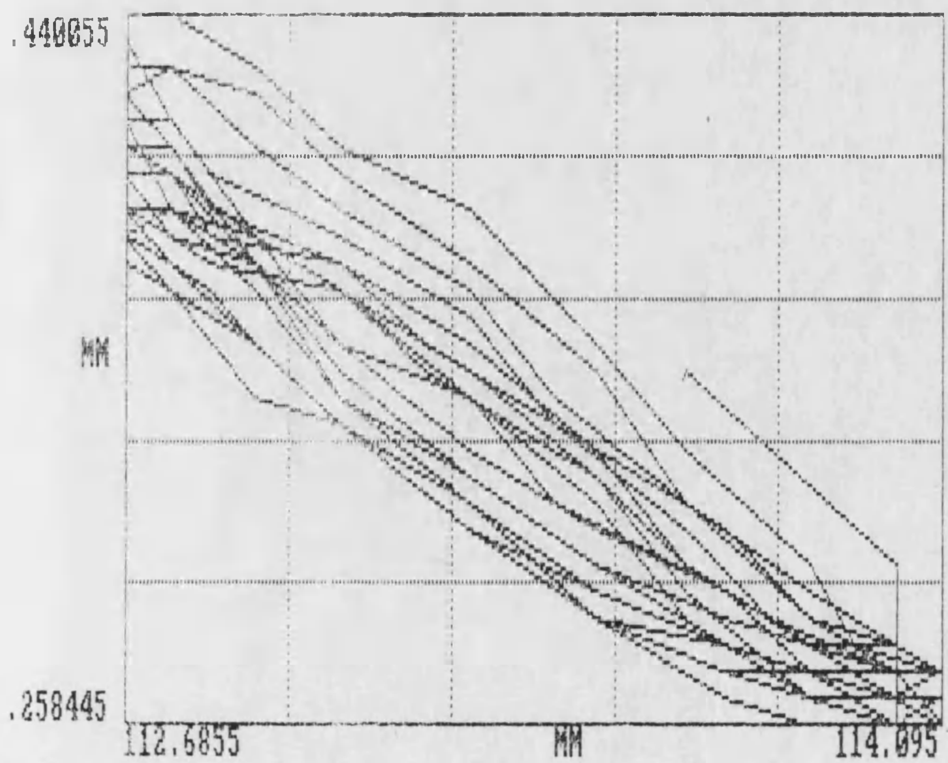


STRING5/16 v STROKE

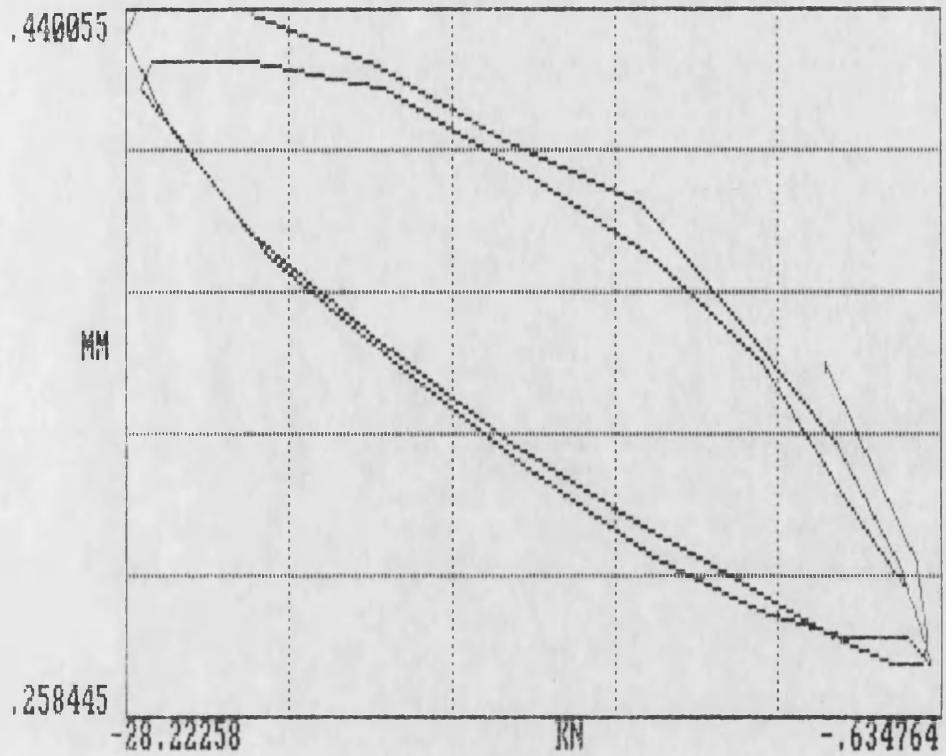


STRING5/16 v STROKE

STRING5/16 v STROKE



STRING5/16 v LOAD



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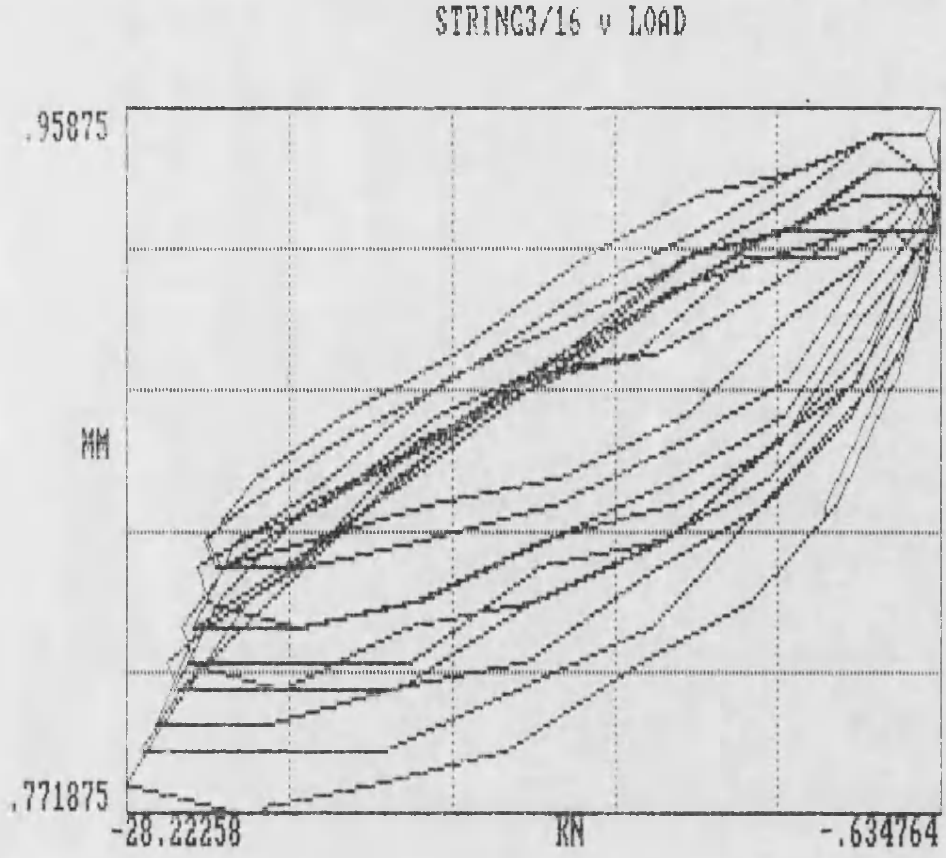
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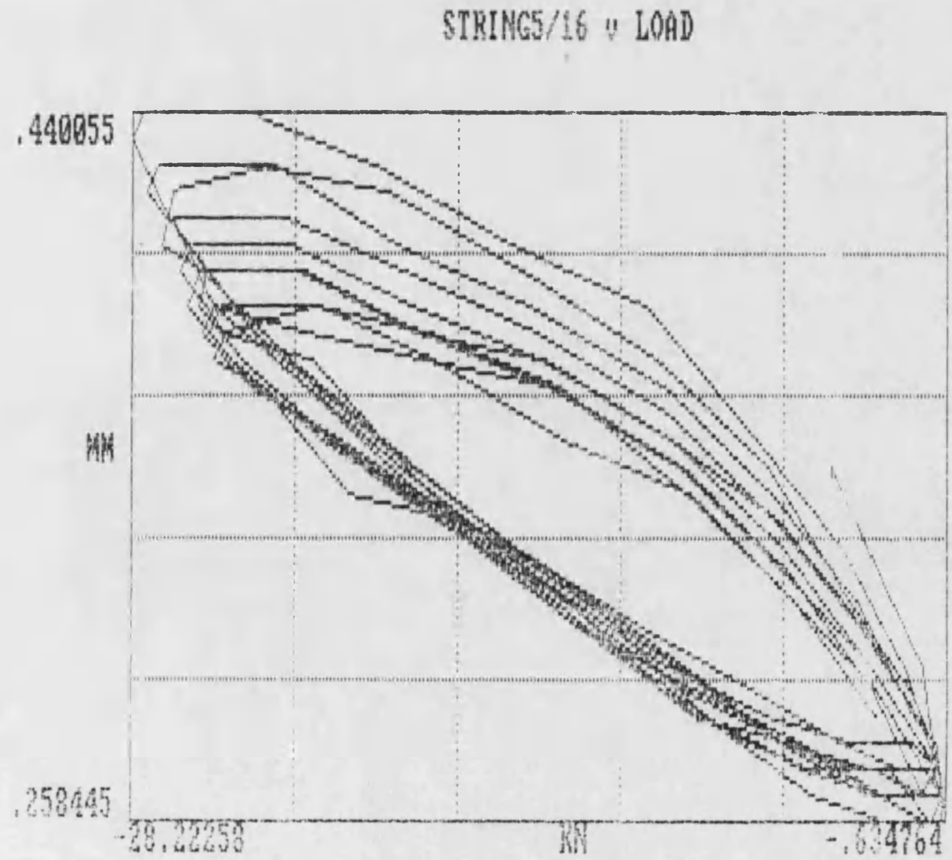
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